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DRILLING PRACTICE
AND
JIG DESIGN

A TREATISE COVERING COMPREHENSIVELY DRILLING AND TAPPING OPERATIONS, AND THE DESIGN OF DRILL JIGS AND FIXTURES FOR INTERCHANGEABLE MANUFACTURE

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PREFACE

In the past, the whole subject of machine shop practice has often been dealt with in a single volume. Today, the new developments in all the branches of the trade would make it impossible to treat the subject comprehensively in so limited a space; instead, a volume is required to adequately cover the practice of each type of machine tool. This book on "Drilling Practice and Jig Design," therefore, deals exclusively with the processes used for producing drilled holes, and the machines, tools, jigs and fixtures employed. The subject of tapping and tapping attachments, so closely allied to drill-press work, has also been adequately covered. Especial attention has been given to the design of jigs and fixtures, because these appliances are indispensable in rapid and accurate work, and are used to a greater extent in connection with drilling operations than in any other branch of machine shop practice. Hence, the book will prove of great value not only to operators of drilling machines, but to tool designers and toolmakers, and to those responsible for the efficiency and the output of the drilling department. The step-by-step method of explaining the principles of jig design has been used, because in this way the subject can be handled in a manner at once clear and comprehensive. Instead of illustrating and describing a miscellaneous collection of jigs and fixtures, the subject has been analyzed, the principles explained, and the details of these devices dealt with as units. This is the only method by which a comprehensive study of the subject can be made.

In preparing this treatise, much of the material published on this subject in MACHINERY's Reference Books has been used, but many amplifications and additions have been made whereever necessary. For the material contained, the Editors are, therefore, largely indebted to a great number of men who have furnished practical information to MACHINERY, and while it would not be feasible to give credit to each individual contributor, it should be mentioned that the framework upon which the chapters on jig design have been built consists of the articles prepared by Mr. Einar Morin, a recognized tool expert and production engineer. To all other writers whose material has appeared in MACHINERY, and which is now used in this book, the Editors hereby express their appreciation.

THE EDITORS.

NEW YORK, *August*, 1915.

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DRILLING PRACTICE AND JIG DESIGN

CHAPTER I

PRINCIPLES OF DRILLING PRACTICE

In the construction of practically all machinery, a great many holes must be drilled, owing to the extensive use of bolts and studs for holding the various parts together. The drilling machines or "drill presses," as they are often called, which are used for drilling these holes, are made in many different types, designed for handling different classes of work to the best advantage, and the various types are also built in a great variety of sizes, as the most efficient results can be obtained with a machine that is neither too small nor too large and unwieldy for the work which it performs.

Upright Drill Press. — An upright drill press of medium size is shown in Fig. 1. The drill itself is inserted in the end of spindle S, and when the machine is in use, this spindle is fed downward either by hand or power, thus causing the revolving drill to cut a hole into the work. The spindle is driven by a horizontal shaft B connecting with a cone pulley P, which is driven by belt from a lower cone pulley P_1. The shaft, on which the lower cone pulley is mounted, is rotated by a belt from an overhead countershaft. The machine is started by shifting this driving belt from the loose pulley C to the "tight pulley" D, which is keyed to the shaft; the position of the belt is controlled by handle A. The speed of the spindle must be varied according to the diameter of the hole being drilled, the speed being increased as the diameter diminishes. To obtain these speed variations, the belt connecting pulleys P and P_1 is shifted to steps of different diameter. The range of speeds obtained in

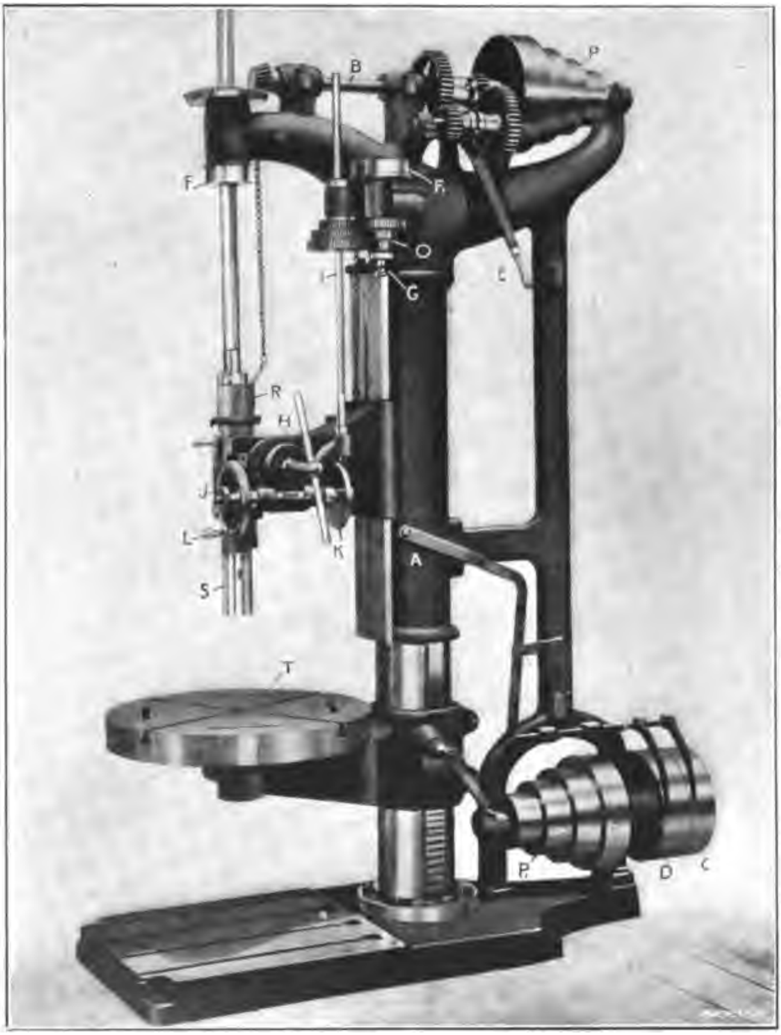

Fig. 1. Hamilton Upright Drilling Machine

this way can be doubled, on this particular machine, by back-gears located just in front of the upper pulley. When these gears are not in use, shaft *B* is coupled direct to cone pulley *P* by means of a sliding clutch *N* (see the detail view, Fig. 3), but when the back-gears are shifted into engagement by operating lever *E*, the clutch is disengaged and the cone pulley drives shaft *B* through train of gears *a*, *b*, *c* and *d*. The fastest speed obtained with the back-gears engaged is slower than the slowest speed when driving direct, so that a gradually increasing range of eight speeds is available.

As the illustration shows, the connection between shaft *B* and the spindle is made by bevel gears. The spindle is free to move vertically through the large bevel gear, and the lower end is steadied by the head *H*, Fig. 1, which is clamped to the column and can be adjusted to different heights. The work-table *T* can also be adjusted vertically on the column to suit the height of the work, and it can be swung to one side when a large heavy part is to be supported directly on the base. After the work is clamped to the table, it can be adjusted for drilling at any point by swinging the table about the column and also by turning the table about its own center. When the table is properly adjusted,

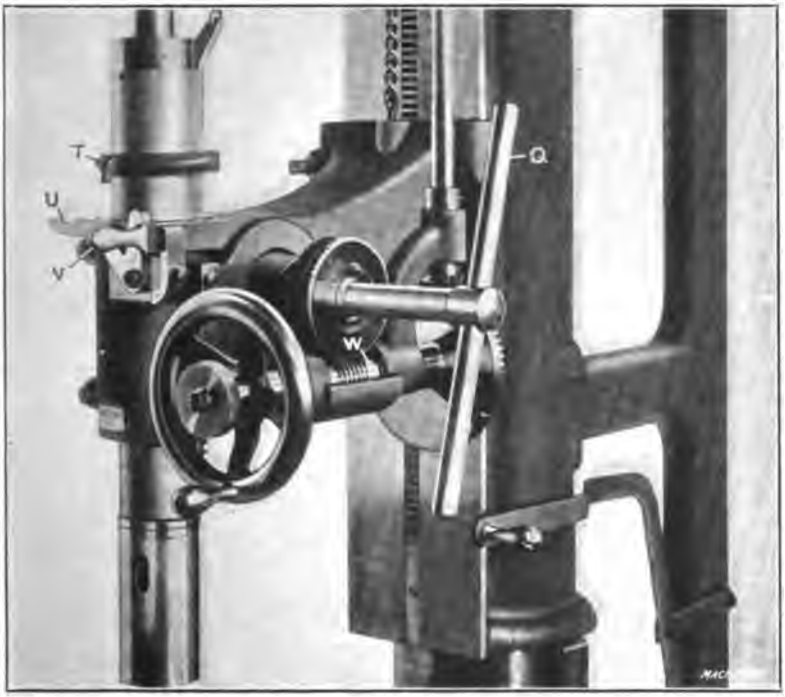

Fig. 2. Drill Spindle Feeding and Automatic Trip Mechanism

it can be clamped to the arm and the arm to the column by the bolts shown.

Power Feed. — The power feed for the spindle is driven by a belt operating on pulleys *F* and F_1. Pulley F_1 is mounted on a shaft carrying a cone of gears *O*, any one of which can be locked to the shaft by changing the position of "pull-pin" *G*. These gears are in mesh with corresponding gears on shaft *I*, which rotates, through bevel and worm-gearing, a pinion meshing with rack *R* attached to the quill in which the spindle revolves. As this pinion rotates, the quill and spindle are moved vertically and the amount of this movement for each revolution can be varied by shifting pull-pin *G*. For example, when a large gear in the cone *O* is locked and becomes the driving gear (by changing the position of the pull-pin), the feed or vertical movement of the spindle is more rapid than when the power is transmitted by one of the smaller gears. The driving gear is locked by a key attached to the pull-pin, and as this key can only engage one gear at a time, the others revolve idly on the shaft. The power feed is engaged or disengaged by tightening or loosening a knurled

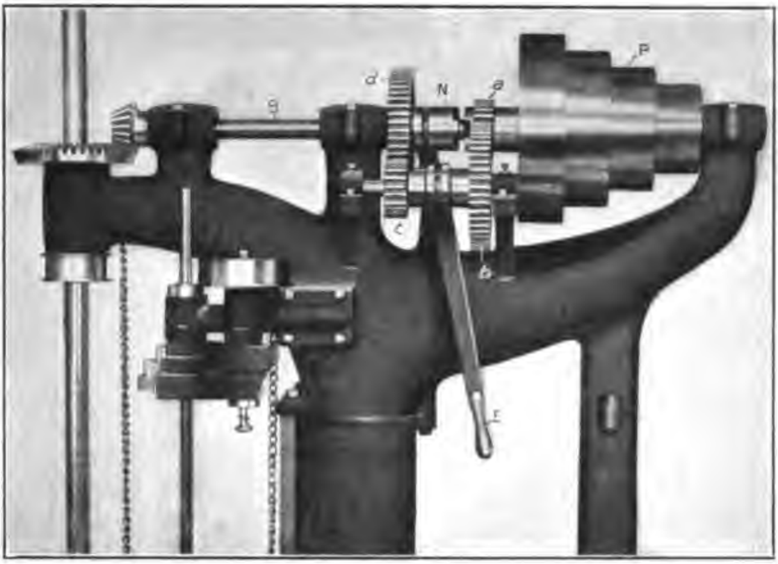

Fig. 3. Back-gearing and Feed Change-gears of Upright Drilling Machine

nut *J*, which controls a friction clutch that connects or disconnects bevel gear *K* with the worm-shaft. When the power feed is disengaged, the spindle can be moved up or down by turning handwheel *L*. On some drilling machines, the vertical feed shaft *I* is driven direct by a belt operating on cone pulleys and the feed changes are obtained by shifting this belt. The spindles of small drill presses usually have only the hand feed, as the power feed is unnecessary when the holes to be drilled are small and not very deep; furthermore such holes can be drilled more rapidly when the spindle is fed by hand.

The machines equipped with power feed usually have some sort of trip mechanism which can be set to automatically disengage the feed when a hole has been drilled to the required depth. The automatic trip or stop on the machine illustrated in Fig. 1 is shown in detail in Fig. 2. This trip has an adjustable collar *T*, the position of which controls the depth of the hole drilled or the point at which the feed is disengaged. This disengagement is effected as follows: When collar *T* strikes the latch *U*, lever *V* is disengaged and worm *W* drops out of mesh with its wheel, thus stopping the feed. The spindle can then be raised quickly for drilling a new hole by turning handle *Q*, which is provided for that purpose. The automatic trip mechanism, after it is properly set, prevents drilling holes deeper than they should be, and close attention on the part of the operator is not required.

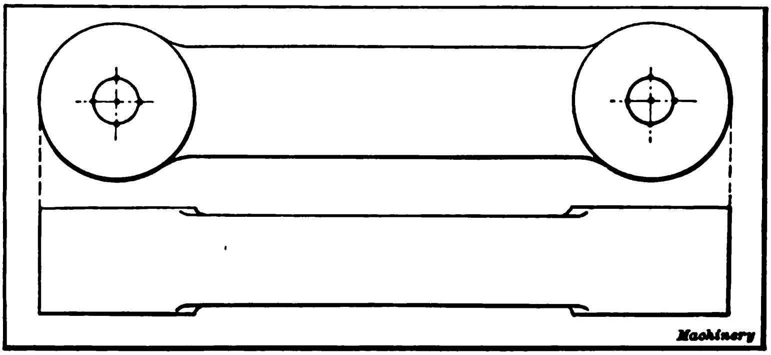

Fig. 4. Example of Drill-press Work

These are the principal features of an upright drill press which, in many respects, is a typical design. Before referring to drilling machines of other types, some examples of drilling will be described.

Example of Drill-press Work. — A simple example of drill-press work is shown in Fig. 4, which illustrates a steel link that is to have holes drilled in the ends. While some form of jig is commonly used for guiding the drill, so that the laying-out and marking of the location of the hole to be drilled on the work is not necessary, we shall assume, in this case, that the location of these holes is indicated by circles previously drawn with dividers and dotted lightly to more clearly show their location. The centers of these circles should first be enlarged with a center-punch to form a starting point for the drill. When the part to be drilled is quite heavy and the holes are comparatively small, it is often unnecessary to clamp the work to the drill-press table, although, as a rule, it is better to use one or more clamps, depending on the shape and size of the work. A method of hold-

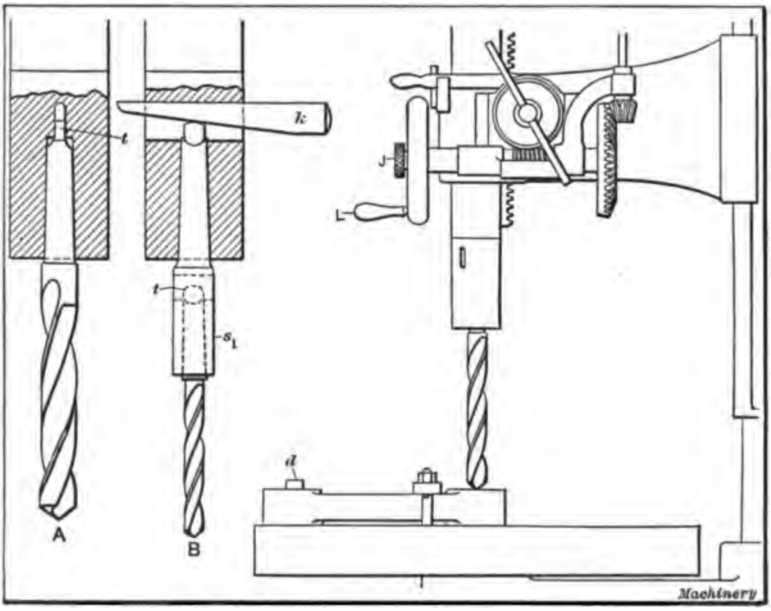

Fig. 5. Method of Holding and Driving Taper-shank Drills. Drilling-head of Upright Machine

ing this particular part, without using any special clamping appliances, is shown in Fig. 5. The end to be drilled is held by a clamp, and a stop *d* is placed against one side of the work to prevent it from rotating with the drill.

The drill itself is inserted either directly in the spindle or in a socket, as will be explained later. The type of twist drill commonly used is shown at *A* in Fig. 6. It has two beveled cutting edges *e* at the end, formed by the two spiral grooves or flutes, and the part *s*, called the shank, is made to a standard taper. The size of the shank is the same on all drills up to a certain diameter, and then a larger shank is used for another range of sizes, and so on. In the Morse system of tapers, which is universally used for twist-drill shanks, the sizes are designated by numbers. For this particular operation, the drill would perhaps be large enough to permit inserting it directly in the spindle as shown at *A* in Fig. 5, although this would depend on the number or size of the taper hole in the spindle. On the other hand, if a comparatively small drill were to be used, it might be necessary to place a socket s_1 (see sketch *B*) in the spindle and insert the drill in the end of this socket. The drill is caused to rotate with the spindle or socket principally by the friction between the shank and the socket into which it fits tightly; this friction

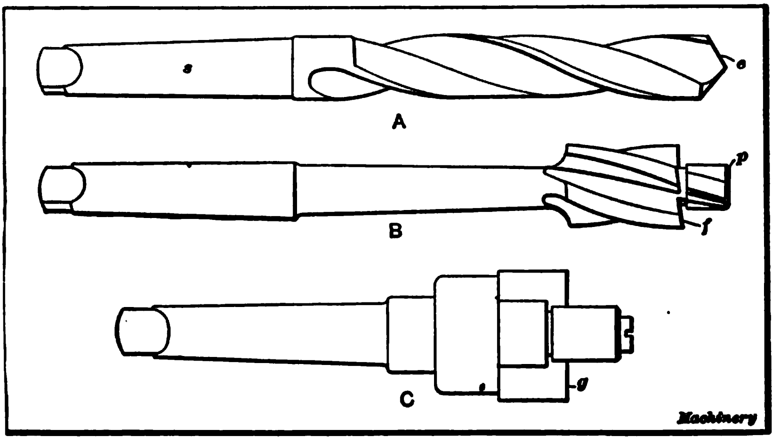

Fig. 6. (A) Twist Drill. (B) Solid Counterbore. (C) Counterbore with Inserted Blade

is assisted by a flat end or tang *t* on the shank, which engages a cross-slot at the end of the taper hole, as shown.

When the drill is in place, it is fed down by handwheel *L* for starting the hole. On some machines this handwheel is replaced by a lever. If the work is clamped in position, it is adjusted for drilling at the proper place by turning the table about its own center and swinging the supporting arm about the column. When the drill begins to cut, the location of the hole with reference to the scribed circle should be noted. If the hole starts off center, as at *A*, Fig. 7, a groove should be cut down that side which is farthest from the circle (see sketch *B*) by using a gouge and hammer, the proper depth of this groove depending on the amount that the hole is off center. This operation is repeated, if necessary, so that the drill will be concentric with the circle (as at *C*) just before it begins to cut to the full diameter. The power feed is then engaged by tightening knob *J*, Fig. 5. When the work rests directly on the table, as in this case, the end to be drilled should be set over a slot or hole, to prevent the drill from cutting the table when it comes through on the lower side. The table and arm should also be clamped after they are properly set. Drills or sockets are removed by a taper center-key or drift *k*, Fig. 5, which is driven in a cross-slot above the tang, as the illustration indicates. When drilling steel or wrought iron, the drill point should be kept lubricated. Sperm or lard oil may be used, and soda water, which is made by dissolving sal soda in water, is also extensively used for lubricating purposes. Cast iron and brass are generally drilled without a lubricant.

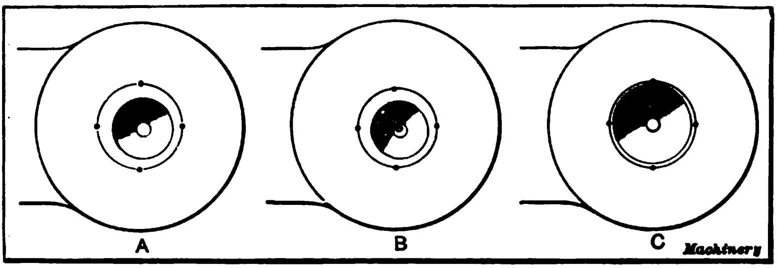

Fig. 7. Method of Starting Drill Concentric with Scribed Circle

Drill Jigs. — It is quite evident that the method of drilling just described would not be efficient if a large number of duplicate parts had to be drilled accurately, as there is likely to be more or less variation in the location of the holes, and considerable loss of time. In the first place, a certain amount of time is required for laying out these holes preparatory to drilling. The operator, when starting the drill, must also be careful to make it cut concentric with the scribed circle, which requires extra time, and there will necessarily be more or less variation. To overcome these objections, jigs are almost universally used for holding the work and guiding the drill, when drilling duplicate parts, especially when large quantities are required. As the number of differently shaped pieces which make up a single machine is often very large, and as most parts require more or less drilling, jigs are made in an almost endless variety of sizes and forms. The shape, in any case, depends upon the form of the work for which the jig is intended and also on the location of the holes to be drilled. A jig in its simplest form is merely a plate containing holes located so as to conform to the positions required for the drilled holes. This jig is simply placed over the part to be drilled and the drill itself is fed down through the different holes. When the holes to be drilled are parallel, and especially if they are in the same plane, a very simple form of flat jig may be employed, but in many cases parts must be drilled on different sides, and frequently castings or forgings are very irregular in

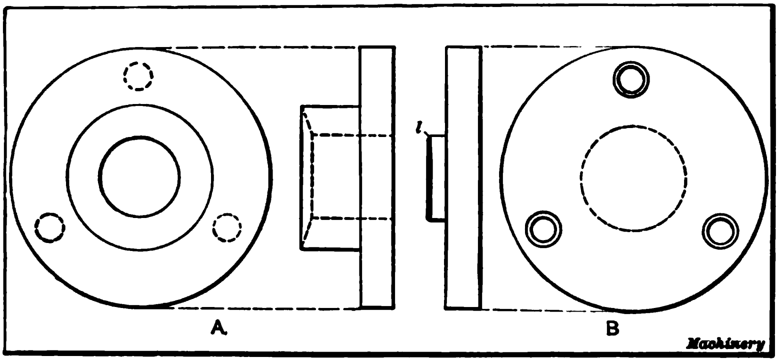

Fig. 8. (A) Packing Gland. (B) Drill Jig for Gland

shape, so that a jig which is made somewhat in the form of a box and encloses the work is necessary, as it enables the guide bushings to be placed on all sides and also makes it comparatively easy to locate and securely clamp the part in the proper position for drilling. A jig of this type is known as a "box jig" and is used very extensively. As is quite evident, the use of a jig not only saves time but also insures accurate and uniform work. As the result of this uniformity, corresponding parts can be drilled so nearly alike that they will interchange, which is, of course, a great aid in assembling a machine and also makes it possible to easily replace a broken member. The subject of drill jigs is treated completely in a number of succeeding chapters.

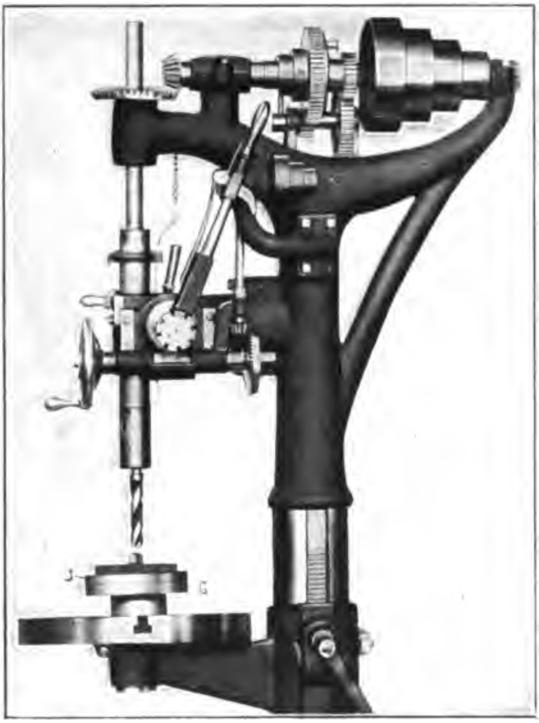
Fig. 9. Drill-press of the Wheel- and Lever-feed Type

Drilling by the Use of Jigs. — An example of drill-press work is shown at *A*, Fig. 8, which illustrates an engine packing gland that is to have three holes drilled through the flange, as indicated by the dotted lines. This work could be done by laying out the three holes and proceeding as described in the foregoing in connection with the link illustrated in Fig. 4, but if a large number of these glands were to be drilled, it would be much better to use a jig for properly locating the drill with reference to the work, without any preliminary laying out operation. A simple form of jig for drilling this flange is shown at *B*. This jig has three holes for guiding the drill, and one side is provided with a round projection *l* which closely fits the hole in the gland, in order to locate the jig in a central position. The method of using the jig is shown in Fig. 9. The gland *G*, with the jig *J* placed on it, is clamped to the table (in this particular instance) by a single clamp and bolt in the center, and the holes are drilled by feeding the drill, successively, through the three holes in the jig.

The holes in jigs are ordinarily lined with hardened steel bushings to eliminate wear. These guide bushings fit the drill closely and keep it in the proper position. Some jigs have fixed guide bushings and others removable bushings. A fixed bushing is shown by the sectional view at *A*, Fig. 10, which also indicates how the drill is guided while it is drilling the work *w*. Jigs are equipped with removable bushings when drills of a different size are to be used or when the drilled holes are to be finished by reaming. For example, if a hole is to be drilled and reamed, a removable bushing is used that fits the drill, as shown at *B*, and this is replaced by a bushing that fits the reamer, as shown at *C*. As previously intimated, a jig is only made when there are quite a number of parts to be drilled, as otherwise the saving effected by it would be more than offset by the expense of making it.

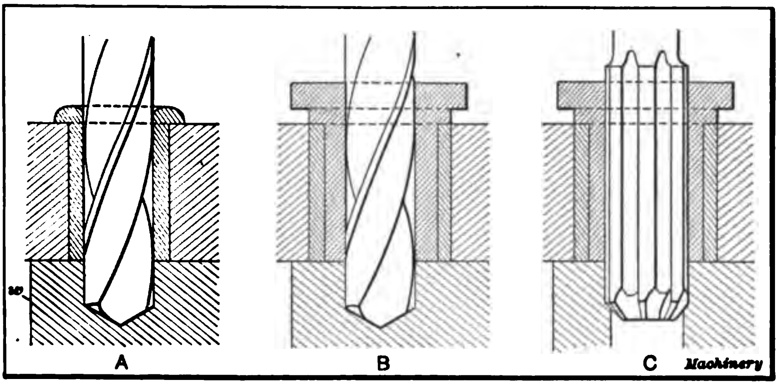

Fig. 10. Fixed and Removable Guide Bushings for Drill Jigs

The ring-shaped jig shown at *A* in Fig. 11 is used for drilling the stud bolt holes in a cylinder flange and also for drilling the cylinder head, which is bolted to the cylinder. The position of the jig when the cylinder flange is being drilled is shown at *B*. An annular projection on the jig fits closely in the cylinder counterbore, as the illustration shows, to locate the jig concentric with the bore. As the holes in the cylinder are to be tapped or threaded for studs, a "tap drill," which is smaller in diameter than the bolt body, is used and the drill is guided by a removable bushing *b* of the proper size. Jigs of this type are often held in position by inserting an accurately fitting plug through the jig and into the first hole drilled, which prevents the jig from turning with relation to the cylinder, when drilling the other holes. When the jig is used for drilling the head, the opposite side is placed next to the work as shown at *C*. This side has a circular recess or counterbore, which fits the projection on the head to properly locate the jig. As the holes in the head must be slightly larger in diameter than the studs, another size of drill and a guide bushing of corresponding size is used. The cylinder is, of course, bored and the head turned before the drilling is done.

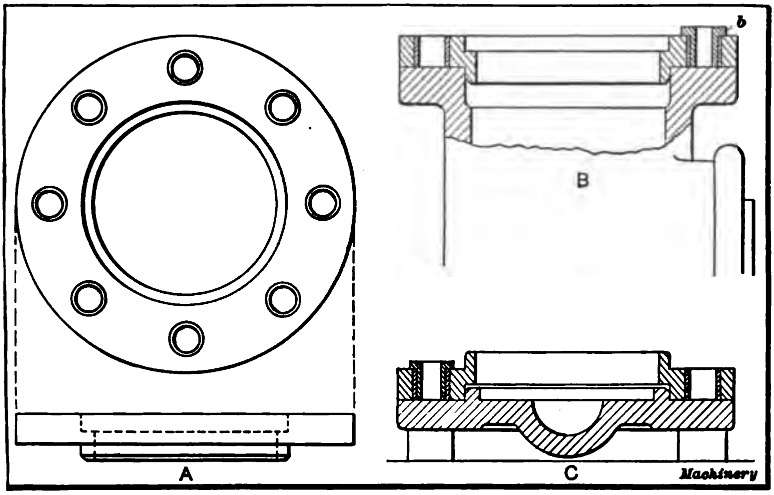

Fig. 11. Jig for Cylinder Flange and Head, and its Application

Using the Work as a Jig. — When two separate parts must have holes drilled in line for bolts or studs, one part can often be used as a sort of jig. To illustrate, suppose a bearing cap and base (see *A*, Fig. 12) are to be drilled for inserting bolts as shown in view *B* to the right. One method would be to first lay out and drill the bolt holes in the cap which we shall assume has been previously planed and fitted. The cap is then clamped in position and the same drill that was used for the bolt holes is fed down to cut a conical spot in the base as at *C*. This "spotting" operation forms a central starting point for the smaller "tap drill," which is then used as indicated at *D*. The drilling of holes which are to be tapped will be referred to later.

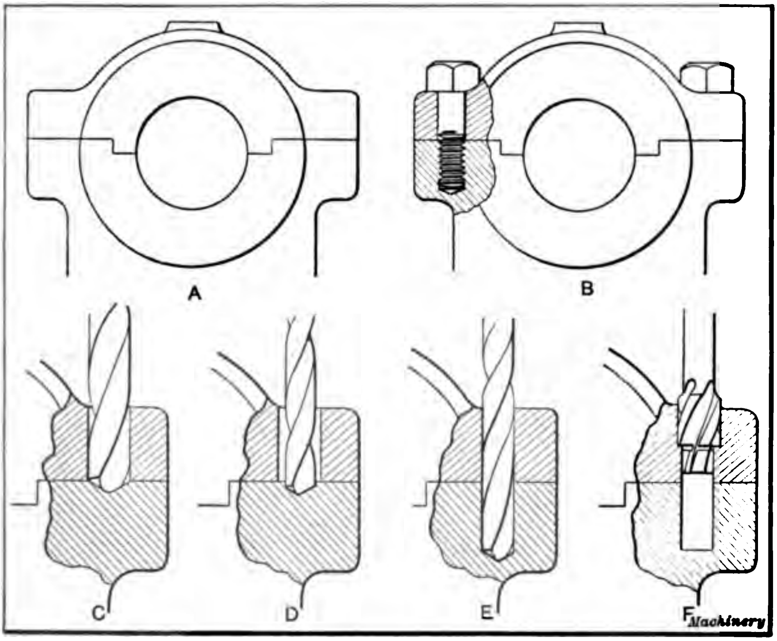

Fig. 12. Views indicating how Work can sometimes be used as a Jig

Another method of drilling this cap and base is shown at *E* and *F*. Both parts are clamped together and drilled with a tap drill as at *E*, after which the cap is removed and the holes are enlarged for the bolts by using a counterbore as indicated at *F*. This type of counterbore is shown in detail in Fig. 6. The cutting is done by the edges *f*, and the guide or pilot *p* fits closely into the hole which the counterbore is to follow, so that the enlarged part of the hole will be concentric. Another type of counterbore is shown at *C*. This style has a single blade or cutter, which cuts along the edges *g*. The blade can be removed by unscrewing the binding screw when it is desired to replace the blade with a different size. Guides or pilots of different diameters can also be attached to the end, as required.

Counterboring and Countersinking. — While drilling machines are intended primarily for drilling holes in solid metal, they are generally used for other operations also, such as counterboring, countersinking, spot-facing, reaming and tapping.

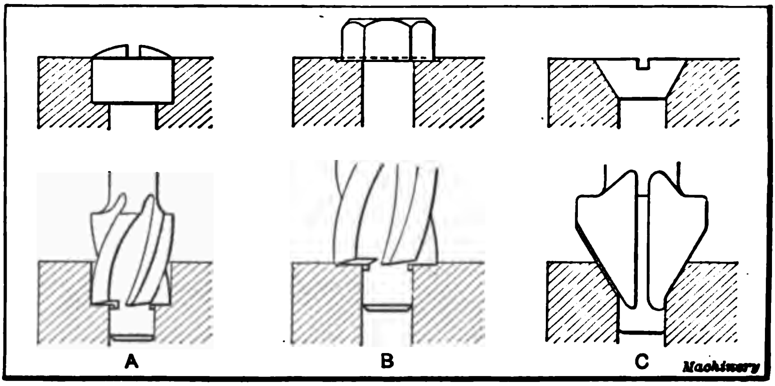

Fig. 13. Use of Counterbore and Countersink

When a hole is enlarged for part of its length, and a square shoulder is formed at the end of the enlarged portion, this operation is known as counterboring. Counterbores are frequently used for enlarging holes to form seats for the heads of screws. A machine screw of the fillister-head type and a method of enlarging a hole which has been previously drilled for the body of the screw are indicated at *A*, Fig. 13. The upper view shows the screw-head in position and the lower view the cutting end of a counterbore after it has been fed to the proper depth. Counterbores are often used for facing a spot around a hole, as indicated at *B*, to provide a true bearing surface for a bolt head. On some classes of work, screws having heads that are conical on the under side are used. Forming a conical seat for a head of this shape is known as countersinking. The operation is similar to counterboring, except that a tool for forming a conical seat is used, as indicated at *C*. The form of countersink shown is used after the hole for the screw-body has been drilled. Countersinks are also used which have a drill of the proper size at the end, instead of a pilot, so that the straight and conical parts of the hole are finished in one operation.

Finishing Holes by Reaming. — Drilled holes are not always round or straight and the diameters vary to some extent, especially when the drill used is sharpened by hand, so that, when accurate holes are required, the drilled hole is finished by reaming, to secure smooth straight holes of uniform diameter. Holes for bolts that must fit accurately are often finished in this way, although on some classes of work, which do not need accurately fitting bolts, a drill slightly larger than the bolt body is used and the reaming operation is omitted.

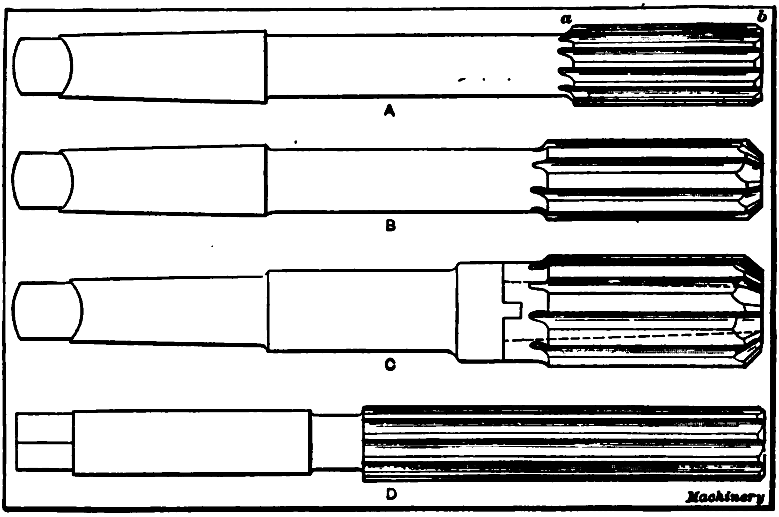

Fig. 14. Reamers of Different Styles

Three different styles of reamers are shown in Fig. 14. The style of reamer shown at *A*, which is known as the fluted type, cuts along the edges *a–b* and it has a taper shank similar to a drill shank, which is inserted in the spindle. This reamer will produce a smooth accurate hole, but it is not adapted to removing much metal, and the diameter of the drilled hole should not be more than 0.010 or 0.015 inch under the finished size. The speed for reaming should be much slower than for drilling, and a fluted reamer should not be forced too hard, as both the tool and work may be injured. Another type of reamer is shown at *B*. This is called a rose reamer and it differs from the fluted type in that the cutting is all done by the beveled edges at the end. The fluted cylindrical body, back of the cutting edges, fits closely into the reamed hole and guides the cutting end. This reamer will remove more metal than the fluted type and it is used for enlarging holes, as well as for truing drilled holes. When very accurate and smooth holes are necessary, the fluted reamer is ordinarily used, but for general purposes the rose reamer is preferable, especially for "machine reaming" when jigs are used. If a fluted reamer is guided by a hardened jig bushing, the cutting edges will be dulled more or less, depending on the alignment between the drilled hole and bushing and the resulting side thrust on the reamer. On the other hand, the rose reamer cannot be injured by the guide bushing, as the cutting edges are on the end only. The shell type of rose reamer shown at *C* has an arbor on which the shell reamer is mounted. The advantage of this arrangement is that reamers of different sizes can be held on the same arbor.

When a very accurate hole is required, it is good practice to ream by hand. One method would be to first drill and rough-ream the hole to within a few thousandths inch of the finished size, and then finish by using a hand reamer *D*. In order to keep the reamer in alignment with the hole, especially when starting, the upper end is sometimes supported by a conical center which is inserted in the spindle.

Drill Sizes. — Regular taper shank drills may be obtained in a great variety of sizes. Many of the small drills used have straight shanks, and the sizes are designated by numbers or letters. A gage is shown in Fig. 15 for measuring drills with numbered sizes, the number of the drill being indicated by the number of the hole which it fits. The difference between the diameters of consecutive sizes represented by this gage only varies from 0.001 to 0.008 inch, so that almost any diameter between the smallest and largest size can be obtained. The decimal equivalents for each number are stamped on the back of the gage shown. Another common form of gage, known as the "jobbers' drill gage," has a series of holes which vary in diameter from $\frac{1}{16}$ inch to $\frac{1}{2}$ inch, the diameters increasing successively by sixty-fourths. The sizes of the different holes are expressed by common fractions which are stamped on the gage. The letter-size drills are made in sets of twenty-six, or from A to Z, and have a difference between consecutive sizes varying from 0.004 to 0.014 inch. Tables giving the corresponding sizes in decimals of an inch, for both lettered and numbered drills, are given herewith.

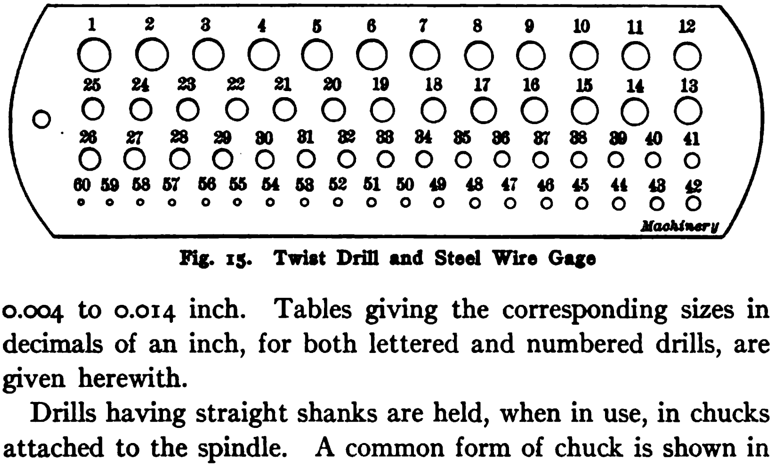

Fig. 15. Twist Drill and Steel Wire Gage

Drills having straight shanks are held, when in use, in chucks attached to the spindle. A common form of chuck is shown in Fig. 17. The drill is held between jaws in the chuck, which are tightened by turning the outer knurled sleeve by hand or with a spanner wrench.

Twist Drill and Steel Wire Gages. — The differences in the gages for small diameter twist drills and steel wire are a constant source of trouble to those who have to deal with drills and steel wire; and gage numbers mean nothing except if the name of the gage employed is specified. Some drill manufacturers are discouraging the use of gage sizes and are asking that the sizes of drills ordered be denoted in decimals of an inch. There are three well-known standards for twist drills and steel wire that

Decimal Equivalents of Letter-size Drills

Letter	Size of Drill in Inches	Letter	Size of Drill in Inches	Letter	Size of Drill in Inches	Letter	Size of Drill in Inches
Z	0.413	S	0.348	L	0.290	E	0.250
Y	0.404	R	0.339	K	0.281	D	0.246
X	0.397	Q	0.332	J	0.277	C	0.242
W	0.386	P	0.323	I	0.272	B	0.238
V	0.377	O	0.316	H	0.266	A	0.234
U	0.368	N	0.302	G	0.261	.....	....
T	0.358	M	0.295	F	0.257	.....	....

Twist Drill and Steel Wire Gage

(Manufacturers' Standard)

No.	Size of Drill in Inches	No.	Size of Drill in Inches	No.	Size of Drill in Inches	No.	Size of Drill in Inches
1	0.2280	21	0.1590	41	0.0960	61	0.0390
2	0.2210	22	0.1570	42	0.0935	62	0.0380
3	0.2130	23	0.1540	43	0.0890	63	0.0370
4	0.2090	24	0.1520	44	0.0860	64	0.0360
5	0.2055	25	0.1495	45	0.0820	65	0.0350
6	0.2040	26	0.1470	46	0.0810	66	0.0330
7	0.2010	27	0.1440	47	0.0785	67	0.0320
8	0.1990	28	0.1405	48	0.0760	68	0.0310
9	0.1960	29	0.1360	49	0.0730	69	0.0292
10	0.1935	30	0.1285	50	0.0700	70	0.0280
11	0.1910	31	0.1200	51	0.0670	71	0.0260
12	0.1890	32	0.1160	52	0.0635	72	0.0250
13	0.1850	33	0.1130	53	0.0595	73	0.0240
14	0.1820	34	0.1110	54	0.0550	74	0.0225
15	0.1800	35	0.1100	55	0.0520	75	0.0210
16	0.1770	36	0.1065	56	0.0465	76	0.0200
17	0.1730	37	0.1040	57	0.0430	77	0.0180
18	0.1695	38	0.1015	58	0.0420	78	0.0160
19	0.1660	39	0.0995	59	0.0410	79	0.0145
20	0.1610	40	0.0980	60	0.0400	80	0.0135

are commonly used at the present time. These are the Stubs steel wire gage, the gage used by the Standard Tool Co., and the gage used by other leading manufacturers, such as the Morse Twist Drill & Machine Co. and Brown & Sharpe Mfg. Co. The latter has been termed, in the accompanying tables, "the manufacturers' standard."

The Stubs steel wire gage is used for measuring steel wire and drill rod, but it is not used as much in this country at the present time as in the past. The gage used by the Standard Tool Co. was originally adopted for drill sizes in this country, but other manufacturers changed the numbers corresponding to certain sizes, while the Standard Tool Co. retained the original numbers, but interpolated half sizes in order to agree as to the actual diameters of drills furnished by other manufacturers. The Standard Tool Co.'s gage agrees with the "manufacturers' standard" for the sizes from No. 1 to No. 60, inclusive, but does not agree with the Stubs steel wire gage. From No. 61 to No. 80, inclusive, it agrees with the Stubs gage, half sizes being omitted. It also agrees with the "manufacturers' standard," as far as the diam-

Table for Comparison of Twist Drill and Wire Gages

Gage Number	Stubs Steel Wire Gage Diam., Inches	Drill Manufacturers' Standard Diam., Inches	Gage Number	Stubs Steel Wire Gage Diam., Inches	Drill Manufacturers' Standard Diam., Inches	Stubs Steel Wire & Standard Tool Co.'s Drill Gage Nos.*	Manufacturers' Standard Drill Gage Nos.	Diam., Inches
1	0.227	0.2280	31	0.120	0.1200	60½	61	0.0390
2	0.219	0.2210	32	0.115	0.1160	61	62	0.0380
3	0.212	0.2130	33	0.112	0.1130	62	63	0.0370
4	0.207	0.2090	34	0.110	0.1110	63	64	0.0360
5	0.204	0.2055	35	0.108	0.1100	64	65	0.0350
6	0.201	0.2040	36	0.106	0.1065	65	66	0.0330
7	0.199	0.2010	37	0.103	0.1040	66	67	0.0320
8	0.197	0.1990	38	0.101	0.1015	67	68	0.0310
9	0.194	0.1960	39	0.099	0.0995	68	....	0.0300
10	0.191	0.1935	40	0.097	0.0980	68½	69	0.0292
11	0.188	0.1910	41	0.095	0.0960	69	....	0.0290
12	0.185	0.1890	42	0.092	0.0935	69½	70	0.0280
13	0.182	0.1850	43	0.088	0.0890	70	....	0.0270
14	0.180	0.1820	44	0.085	0.0860	71	71	0.0260
15	0.178	0.1800	45	0.081	0.0820	71½	72	0.0250
16	0.175	0.1770	46	0.079	0.0810	72	73	0.0240
17	0.172	0.1730	47	0.077	0.0785	73	....	0.0230
18	0.168	0.1695	48	0.075	0.0760	73½	74	0.0225
19	0.164	0.1660	49	0.072	0.0730	74	....	0.0220
20	0.161	0.1610	50	0.069	0.0700	74½	75	0.0210
21	0.157	0.1590	51	0.066	0.0670	75	76	0.0200
22	0.155	0.1570	52	0.063	0.0635	76	77	0.0180
23	0.153	0.1540	53	0.058	0.0595	77	78	0.0160
24	0.151	0.1520	54	0.055	0.0550	78	....	0.0150
25	0.148	0.1495	55	0.050	0.0520	78½	79	0.0145
26	0.146	0.1470	56	0.045	0.0465	79	....	0.0140
27	0.143	0.1440	57	0.042	0.0430	79½	80	0.0135
28	0.139	0.1405	58	0.041	0.0420	80	....	0.0130
29	0.134	0.1360	59	0.040	0.0410	.....	....	....
30	0.127	0.1285	60	0.039	0.0400	.....	....	....

* Half sizes are included only in Standard Tool Co.'s gage.

eters used are concerned, but the numbers corresponding to given diameters are different.

Oil Drills. — As previously stated, a lubricant, such as oil or soda water, should be applied to the drill point when drilling iron and steel, in order to secure efficient results. Ordinarily the lubricant is injected in the hole and runs down the drill flutes to the cutting end, but when a deep hole is being drilled, this method is unsatisfactory, as the chips which are carried upward to the surface by the spiral grooves tend to prevent the lubricant from reaching the drill point. To overcome this difficulty, twist drills are made having internal oil holes, as shown by the dotted lines, Fig. 16, which lead the lubricant directly to the cutting end. A special socket *S* is used for an oil drill, having a stationary collar *c* which is connected with a pipe and hose leading to the source of supply. This collar has an annular groove located opposite holes in the revolving socket, which permits the lubricant to enter holes in the drill shank. The lubricant is either

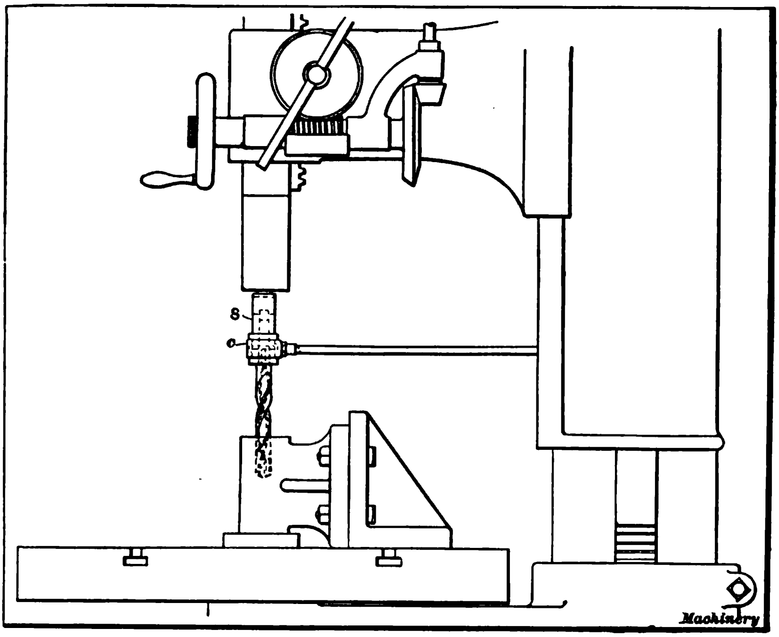

Fig. 16. Method of Applying Oil-tube Drill to Drill-press

supplied by a pump or it is fed by gravity from a bucket suspended above the drill.

The method employed for drilling oil holes in twist drills is interesting. These holes are drilled before the drill is fluted, the drills afterwards being rough-fluted with straight flutes, the drill then twisted, and finally finished in the usual manner. The drilling of the oil holes is done progressively by small twist drills, arranged in order of length, each drill deepening the hole made by its predecessor only ½ or ¾ inch. The hole is begun by a short stiff drill which starts the hole perfectly true, and the following drills are guided by the sections of the hole first drilled. This practice eliminates the use of a long, slender drill for drilling the first part of the hole, and enables the drilling to be done much faster than would otherwise be possible.

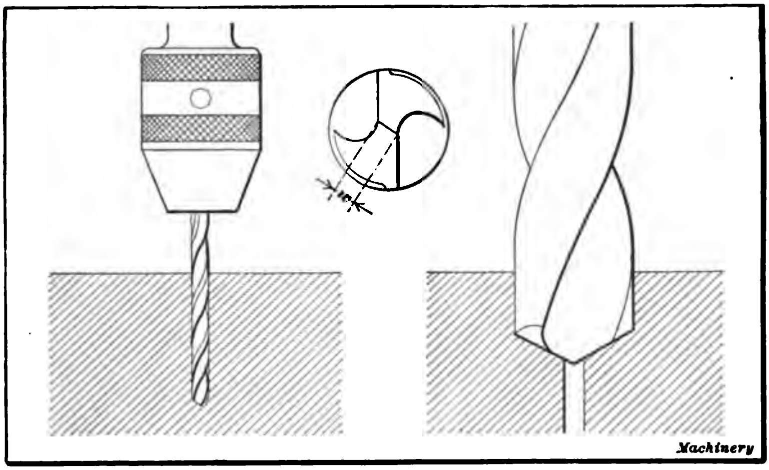

Fig. 17. **Pressure for Feeding Large Drill can be reduced by Drilling Small "Lead Hole"**

Drilling Large Holes. — The pressure required for feeding a large drill is considerable, but it can be greatly reduced and the drill be made to cut faster, by first drilling a small "lead hole," as shown in the view to the left, Fig. 17. The diameter of this lead hole should be as large as, or a little larger than, the width *w* of the drill point, because this point does not have the keenness of the cutting edges and merely scrapes the metal, so that the pressure necessary to force it downward is comparatively great. The lead hole relieves this excessive pressure and permits all the thrust to come directly on the cutting edges of the drill, as indicated by the sectional view to the right.

Special Drills. — Large holes are sometimes drilled about one-half or two-thirds the required size by first using an ordinary two-groove drill, which is then followed by a three- or four-groove drill similar to the one shown at *A*, Fig. 18. This type is only used for following smaller drills or for enlarging cored holes, and it is not adapted for drilling holes into solid stock.

A drill is shown at *B* in Fig. 18, having two straight flutes instead of the spiral form. This type is used to advantage for the drilling of brass or thin sheet metal. Ordinarily, twist drills, owing to the acute angles of the cutting edges, tend to "dig in" or catch, especially when coming through the lower side of a thin plate, but this is largely overcome by the straight-fluted type, as the cutting edges do not have the rake or slope common to twist drills. Sometimes the cutting edges of twist drills are ground flat at the front for drilling brass or thin sheet metal.

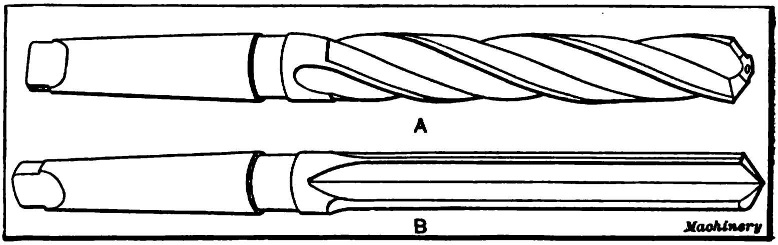

Fig. 18. (A) Three-groove Drill. (B) Straight-fluted Drill

Speed of Drills. — The proper speed for a drill depends on its diameter and the kind of material being drilled. The table, "Drilling Speeds — Carbon Steel Drills," gives the speeds in revolutions per minute, for drills ranging from $\frac{1}{16}$ inch to 3 inches in diameter, when drilling wrought iron, steel, cast iron or brass. It may be necessary to vary these speeds somewhat in accordance with the hardness of the metal. Some castings, for example, are soft and others very hard, so that it is not possible to give speeds which will apply under all conditions. If the speed is too high, this will be shown by the action of the drill and the wear on the cutting edge. Oil drills can usually be run about 25 per cent faster than the speeds listed. Drills made from "high-speed" steel can also be run at much higher speeds than those made from ordinary carbon steel.

The following points should be carefully observed to obtain the best results. If the drill has a tendency to wear away on the outside, it is running too fast, and if it breaks or chips on the cutting edges, the feed is too coarse. Wear on the outer corners of a drill, as the result of excessive speed, is especially noticeable when drilling cast iron. In many cases, however, it is preferable to operate drills at speeds which approach the corner wearing point, using a light feed rather than a comparatively slow speed and heavier feed. This practice is recommended especially when drilling in automatic machines, provided the holes are flooded with lard oil. When the depth of

Drilling Speeds — Carbon Steel Drills

Drill Diam., Inches	Iron, Steel, 30 Feet	Cast Iron, 35 Feet	Brass, 60 Feet	Drill Diam., Inches	Iron, Steel, 30 Feet	Cast Iron, 35 Feet	Brass, 60 Feet
	Revolutions per Minute				Revolutions per Minute		
1/16	1830	2140	3665	1 1/2	75	90	155
1/8	915	1070	1835	1 9/16	75	85	145
3/16	610	715	1220	1 5/8	70	80	140
1/4	460	535	915	1 11/16	70	80	135
5/16	365	430	735	1 3/4	65	75	130
3/8	305	355	610	1 13/16	65	75	125
7/16	260	305	525	1 7/8	60	70	120
1/2	230	265	460	1 15/16	60	70	120
9/16	205	240	405	2	55	65	115
5/8	185	215	365	2 1/16	55	65	110
11/16	165	195	335	2 1/8	55	65	110
3/4	155	180	305	2 3/16	50	60	105
13/16	140	165	280	2 1/4	50	60	100
7/8	130	155	260	2 5/16	50	60	100
15/16	120	145	245	2 3/8	50	55	95
1	115	135	230	2 7/16	45	55	95
1 1/16	110	125	215	2 1/2	45	55	90
1 1/8	100	120	205	2 9/16	45	50	90
1 3/16	95	115	195	2 5/8	45	50	85
1 1/4	90	105	185	2 3/4	40	50	85
1 5/16	85	100	175	2 7/8	40	45	80
1 3/8	85	95	165	3	40	45	75
1 7/16	80	95	160	......	......	......	......

the holes exceeds twice the diameter, the chips are removed with greater difficulty, and it is preferable to apply slower speeds and heavier feeds as the depth increases. When drilling brass, use a comparatively heavy feed, especially on automatic machines. If the drills are lubricated, a copious supply of the lubricant should be used.

As to speeds and feeds in general, high-speed steel does not necessarily give the best results when working at the maximum speed. High-speed steel drills might be run at 100 feet per minute, but it is usually better to reduce the speed to from 60 to 70 feet per minute, especially when starting. The speed, however, depends to some extent upon the rigidity and power of the drilling machine available, and the quality of the drill must also be considered.

Feeds for Drills. — An approximate idea of the feed to use for the various drill diameters, under ordinary conditions, may be obtained from the following figures: A ¼-inch drill should have a feed of about 0.005 inch, a ½-inch drill, 0.007 inch, and a ¾-inch drill, 0.010 inch per revolution of the spindle. The amount of feed, as well as the drilling speed, varies greatly, not only because of the difference in metals, but also because of the variations as to power and rigidity of drilling machines.

Results of Drilling Tests. — The following results of a test illustrate the possibilities of rapid drilling when using a high-grade drill and a powerful and rigid machine. A 1½-inch twist drill was driven through a piece of 0.35 to 0.40 per cent carbon steel, 4 inches in thickness, at a speed of 343 revolutions per minute and a feed of 0.061 inch per revolution. This means that the drill was advanced at a rate of 20.92 inches per minute. Three holes were drilled at this rate, and after the third hole was finished the drill was still in good condition and could have drilled several more holes at the same rate without the necessity of sharpening. Another make of drill of the same size was put in the machine and two holes were drilled at the same speed and feed. After drilling two holes, this drill was still in fair condition and would easily have drilled another hole under the same conditions without the necessity of sharpening.

Speeds and Feeds for Drilling *

High-speed Steel Drills

Size of Drill	Feed per Rev.	Bronze, Brass, 300 Feet	Cast Iron, Annealed, 170 Feet	Cast Iron, Hard, 80 Feet	Mild Steel, 120 Feet	Drop Forg., 60 Feet	Mal. Iron, 90 Feet	Tool Steel, 60 Feet	Cast Steel, 40 Feet
Inches	Inches	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
1/16	0.003	.....	.....	4880	....	3660	....	3660	2440
1/8	0.004	.....	5185	2440	3660	1830	2745	1830	1220
3/16	0.005	.....	3456	1626	2440	1210	1830	1220	807
1/4	0.006	4575	2593	1220	1830	915	1375	915	610
5/16	0.007	3660	2074	976	1464	732	1138	732	490
3/8	0.008	3050	1728	813	1220	610	915	610	407
7/16	0.009	2614	1482	698	1046	522	784	522	348
1/2	0.010	2287	1296	610	915	458	636	458	305
5/8	0.011	1830	1037	488	732	366	569	366	245
3/4	0.012	1525	864	407	610	305	458	305	203
7/8	0.013	1307	741	349	523	261	392	261	174
1	0.014	1143	648	305	458	229	349	229	153
1 1/4	0.016	915	519	244	366	183	275	183	122
1 1/2	0.016	762	432	204	305	153	212	153	102
1 3/4	0.016	654	371	175	262	131	196	131	87
2	0.016	571	323	153	229	115	172	115	77

Carbon Steel Drills

Size of Drill	Feed per Rev.	Bronze, Brass, 150 Feet	Cast Iron, Annealed, 85 Feet	Cast Iron, Hard, 40 Feet	Mild Steel, 60 Feet	Drop Forg., 30 Feet	Mal. Iron, 45 Feet	Tool Steel, 30 Feet	Cast Steel, 20 Feet
Inches	Inches	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
1/16	0.003	.....	5185	2440	3660	1830	2745	1830	1220
1/8	0.004	4575	2593	1220	1840	915	1375	915	610
3/16	0.005	3050	1728	813	1220	610	915	610	407
1/4	0.006	2287	1296	610	915	458	636	458	305
5/16	0.007	1830	1037	488	732	366	569	366	245
3/8	0.008	1525	864	407	610	305	458	305	203
7/16	0.009	1307	741	349	523	261	392	261	174
1/2	0.010	1143	648	305	458	229	343	229	153
5/8	0.011	915	519	244	366	183	275	183	122
3/4	0.012	762	432	204	305	153	212	153	102
7/8	0.013	654	371	175	262	131	196	131	87
1	0.014	571	323	153	229	115	172	115	77
1 1/4	0.016	458	260	122	183	92	138	92	61
1 1/2	0.016	381	216	102	153	77	106	77	51
1 3/4	0.016	327	186	88	131	66	98	66	44
2	0.016	286	162	77	115	58	86	58	39

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According to the Cleveland Twist Drill Co., the apparent hardness of a drill, which varies with the composition of the steel, is no indication of its power to stand up under the cut. A high-speed drill that cannot be filed may be made to drill extremely hard material by exercising great care, but it is so brittle as to be worthless for softer material. Numerous tests have proved that files vary in hardness quite as much as other hardened tools, and for this reason file tests are unreliable. No drill that files hard or soft should be condemned for this reason alone, but should be first given a drilling test in material of known hardness.

Care of High-speed Steel Drills. — The recommendation is made that high-speed drills be warmed before using, especially where the conditions of service are severe. Any hard piece of steel is brittle when cold, and high-speed drills are no exception. They work better when warm, often giving good results when the chips are turned blue by the heat generated. Never turn cold water onto a high-speed drill, as it is very likely to crack. It is also bad practice to plunge a drill into cold water after the point has been heated in grinding. The drill may be impaired by starting a number of fine cracks at the point.

Drilling Speeds and Feeds Recommended by Drill Manufacturers. — The Cleveland Twist Drill Co. recommends the following speeds and feeds as a guide, until more definite data can be obtained in actual practice: Start at a moderate speed and feed. For carbon-steel twist drills, when drilling soft tool or machine steel, use a peripheral speed of 30 feet per minute; for cast iron, 35 feet; for brass, 60 feet. Use a feed of from 0.004 to 0.007 inch per revolution for drills ½ inch and smaller, and from 0.005 to 0.015 inch per revolution for drills larger than ½ inch. High speeds in cast iron tend to wear away the "land" of the drill, and 35 feet per minute peripheral speed should not be exceeded for carbon-steel drills. In the case of high-speed drills, the foregoing feeds should remain unchanged, but the speeds should be increased from two to two and one-half times. With these speeds and feeds as a starting point, the maximum results should be obtained by noting the condition of the drill.

The Standard Tool Co. recommends the following speeds and feeds: Start high-speed steel drills at peripheral speeds of from 50 to 70 feet per minute, for wrought iron and steel; from 60 to 80 feet per minute, for cast iron; and 140 feet per minute, for brass. After a few holes have been drilled, these speeds may be increased as much as conditions will permit, better results being obtained by allowing the drills to reach the maximum speed gradually. The feeds recommended are as follows: For wrought iron and steel, 0.004 inch per revolution for $\frac{1}{16}$-inch drill; 0.005 inch for $\frac{1}{4}$-inch drill; 0.008 inch for $\frac{1}{2}$-inch drill; 0.010 inch for 1-inch drill; 0.015 inch for 2-inch drill.

High-speed Drilling of Small Holes. — A phase of drilling practice which has received comparatively little attention until recently is that concerning the production of very small holes. Many drilling machines have been built for quickly drilling holes from one-quarter inch diameter up, but few that would drive a drill at efficient speed in the very small sizes. The law of efficient drill action holds approximately true for any diameter of drill. If a high-speed steel drill of one inch diameter should be driven at the rate of 300 revolutions per minute, or at a peripheral speed of 80 feet per minute, then a drill $\frac{1}{32}$ inch in diameter should be run at the rate of nearly 10,000 revolutions per minute to attain the same peripheral speed. But this speed was practically impossible with the drilling machines having plain spindles, indifferently balanced pulleys, and other defects tolerable in comparatively slow-running machinery.

The new type of drilling machine capable of driving the smallest commercial twist drills at efficient speeds is a highly specialized tool, built very accurately and carefully balanced throughout. Ball bearings provided for taking thrusts rather than radial loads on the spindle are features of novelty to the machine designer and user. The result of intelligent design and high-grade workmanship is that holes so small that they can be drilled with ordinary machines only by painstaking care, and then at the cost of many broken drills, are being drilled at "punching machine" speeds.

A feature of high-speed drilling requiring accurate balancing

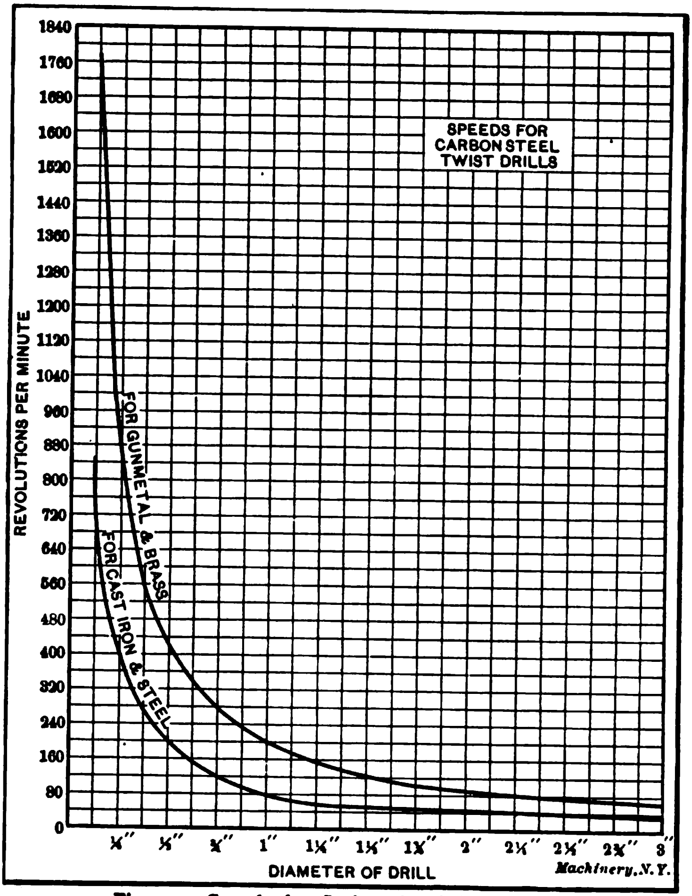


Fig. 19. Speeds for Carbon Steel Twist Drills

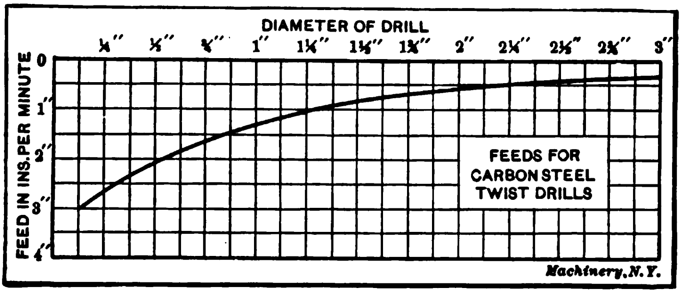


Fig. 20. Feeds for Carbon Steel Twist Drills

is the drill chuck. The ordinary drill chuck balanced for speeds of 2000 to 3000 revolutions per minute was found to be out of balance at 10,000 revolutions per minute and great care had to be taken to secure perfectly balanced chucks before satisfactory results could be obtained. The case is interesting because the drilling machine has often been regarded as a simple tool that could be built anywhere by cheap labor. The fact is that it is a machine requiring the best design and workmanship in order to produce efficiently, especially in the small sizes.

Diagrams of Speeds and Feeds. — The accompanying charts give actual working speeds and feeds and represent good general practice. They are based on the principle of obtaining the maximum cutting efficiency compatible with reasonable life of the drill. On the whole, the aim, in selecting these speeds and feeds, has been to use moderate speeds and heavy feeds, as chips take a great deal less power to produce than powder. The rubbing action which takes place with fine feeds soon spoils the cutting edge.

Drilling Lubricants. — It is essential that the drill be properly flooded with some kind of lubricant when drilling steel or wrought iron. Nothing better than a good grade of lard oil has been found for drilling soft and medium steel. It is too expensive, however, for general use. Cotton-seed oil is even better as a conductor of heat, but it gums so badly that it is impracticable if used alone. Soap-suds is an excellent lubricant for drop-forgings, malleable iron, mild steel, and cast steel. The different drilling compounds on the market are to a greater or less extent merely compositions of animal or vegetable oils with cheap mineral or lubricating oils, or else they are soapy emulsions. There is a great difference of opinion as to the essential properties of drilling compounds, some claiming that the function is solely that of cooling, whereas others contend that the compound should both cool and lubricate. Under ordinary drilling conditions, the compound often does not reach the actual cutting edges of the drill, but if there is a lubricant in the compound, it undoubtedly aids in reducing the friction of the drill in the hole and also expedites the passage of the chips.

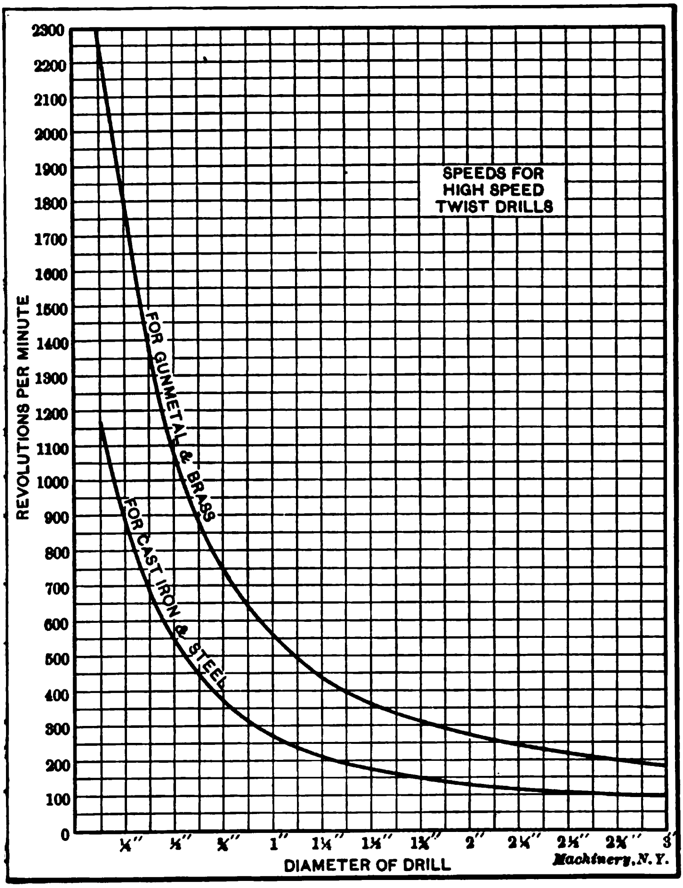


Fig. 21. Speeds for High-speed Twist Drills

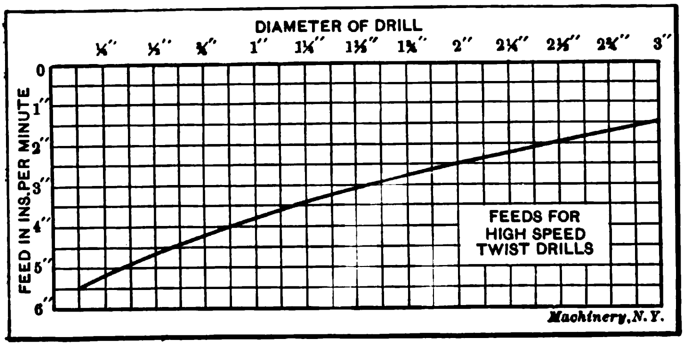


Fig. 22. Feeds for High-speed Twist Drills

The following are recommended for different materials: When drilling hard and refractory steel, use turpentine, kerosene or soda water; for soft steel and wrought iron, lard oil or soda water; for malleable iron, soda water; for brass, a flood of paraffin oil, if any lubricant is used; for aluminum and soft alloys, kerosene or soda water. Cast iron should be worked dry, or with a jet of compressed air as a cooling medium. When drilling very deep holes in cast iron, a few drops of kerosene deposited on the drill point will be found useful; but care must be taken to use a very small amount of the lubricant. The drilling of hard material is facilitated by using turpentine as a cutting compound and by grinding off the sharp angles of the cutting edges so as to permit quite heavy feeds without chipping the edges. This form of point will also be found advantageous for drilling soft material, like brass, as it does not tend to dig into the metal. It is good practice to warm the lubricant before using it on high-speed steel tools.

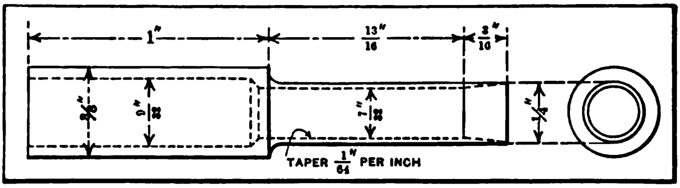


Fig. 23. Drill for Paper

Drill for Paper. — The tubular drill shown in Fig. 23 is adapted for drilling holes in paper leaves, the particular size shown being used for loose-leaf ledger work in preference to punching. The outside diameter, which corresponds to the size of hole required, has a total taper of 0.001 inch per inch, and the inside or bore tapers $\frac{1}{64}$ inch per inch. To provide clearance, the bore of the drill shank is enlarged $\frac{1}{16}$ inch to allow the scrap or paper cuttings to pass through freely. The cutting end is beveled on the inside to form a sharp edge. The drill should be hardened in oil and drawn to a dark brown at the cutting edge, this color running off gradually to a blue at the back end of the tube. This drill should run about 1500 revolutions per minute.

Drilling Marble. — The drilling of marble and similar materials, especially when the drill is fed by hand, is greatly facilitated by grinding or filing a narrow slot in the point of the drill, as shown in Fig. 24. This slot should be about $\frac{1}{8}$ to $\frac{1}{4}$ inch deep, according to the size of the drill, and at an angle of a little less than 90 degrees with the cutting edges. If the slotting is carefully done, the drill will give good results.

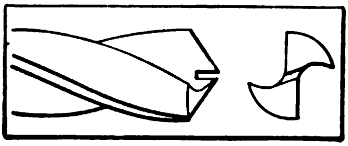


Fig. 24. Drill Ground for Drilling Marble

Drill for Brick. — Fig. 25 shows a cheap and serviceable form of drill for brick walls, which can be made from wrought iron, gas or steam pipe. A solid plug is welded in one end to close it up and serve as a head for the drill, and the other end is serrated in the same manner as a hollow mill or core drill, and slightly spread to give it clearance. As the drill is made from wrought iron, ordinary methods of hardening are of little use; but by heating the working end of the drill to a fusing temperature, along with a piece of thin cast iron, and allowing them to come in contact while in the fire, part of the cast iron will adhere to the wrought iron and can be pretty evenly distributed over the teeth by turning the drill. After a fair coating of the cast iron has adhered to the teeth, remove the drill from the fire, shake it or give it a light rap upon something solid to remove any surplus cast iron, and insert in a cold water bath. The teeth of a drill treated in this manner are so hard that they cannot be touched with a sharp file, and will wear until the rest of the drill is completely worn out if it is not subjected to heavy hammering.

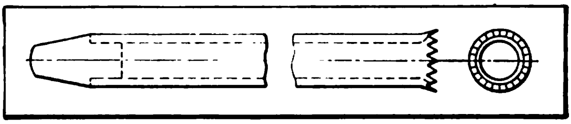


Fig. 25. Drill for Brick

Drilling Holes in Glass. — There are several methods of drilling holes in glass. For holes of medium and large size, use brass or copper tubing having an outside diameter equal to the size of hole required. Revolve the tube at a peripheral speed of about 100 feet per minute, and use carborundum (80 to 100 grit) and light machine oil between the end of the pipe and the glass. Insert the abrasive under the drill with a thin piece of soft wood, to avoid scratching the glass. The glass should be supported by a felt or rubber cushion not much larger than the hole to be drilled. If practicable, it is well to drill about halfway through and then turn the glass over and drill down to meet the first cut. Any fin that may be left in the hole can be removed with a round second-cut file wet with turpentine. For comparatively small holes, a solid drill is often used. Use steel rod or an old three-cornered file, grinding the end to a long tapering triangular shaped point. Grip the drill in a chuck and rotate rapidly. Use a mixture of turpentine and camphor as a lubricant. Holes up to ½ inch in diameter can be drilled in glass with a flat drill which has been hardened in sulphuric acid, a mixture of turpentine and camphor being used as a lubricant.

Ordinary twist drills are also used for drilling glass, the turpentine and camphor mixture being used as a lubricant. The glass is drilled about halfway through and then turned over so that the remaining depth may be drilled from the opposite side. No jig or fixture is required for this purpose. When the glass is turned over, the bottom of the hole will be clearly shown by a white spot, and by centering the drill on this spot, a good clean hole can be produced. Blotting paper is sometimes placed beneath the glass while drilling to produce an even support.

Strength of Drilled Parts. — Tests made in France indicate that when holes are drilled and then reamed in soft steel, the metal between the holes increases on an average of nine per cent in its ultimate strength and twelve per cent in its elastic limit. This condition is explained as being due to the fact that the metal is compressed and thus offers a higher tensile resistance to rupture. Hence, if several holes are drilled, so as not to injure the material as in punching, the average tensile strength of the section across the holes per unit area of metal will be higher than before the holes were drilled.

CHAPTER II

TYPES OF DRILLING MACHINES

Drilling machines may be divided into three general or main classes, upright drills, radial drills, and multiple-spindle drills. Each of these main classes may be further subdivided into a number of different types. There are also a number of special drilling machines which do not belong to any of the three main classes mentioned. An upright drilling machine of usual design has been illustrated and described in Chapter I. It is not necessary, therefore, to describe this type of machine in this chapter.

Radial Drilling Machines. — Radial drilling machines may be of two special types, plain radial and universal radial. What is known as a plain radial drilling machine is illustrated in Fig. 1. This type differs from the vertical machine illustrated in Fig. 1, Chapter I, in that the drilling head is so mounted that it can be moved to the required position for drilling, instead of adjusting the work or table each time a new hole is to be drilled. Because of this feature, the radial drill is especially adapted to heavy work, as a number of holes can be drilled by simply adjusting the drill head to the proper position. This drill head, which contains the spindle *S*, is mounted on an arm *A* carried by an outer column *B*, which, with the arm, can be turned about a stationary inner column attached to the base. The head can also be traversed along the arm, and this radial adjustment, combined with the swinging movement of the arm about the column, makes it possible to set the drill spindle in any position within the range of the machine. The drill spindle is driven, indirectly, by a belt operating pulley *P*. The shaft carrying this pulley drives, through gearing, a lower shaft *C* which transmits the movement, by means of bevel gears, to a vertical internal shaft which extends to the top of the column. At this point connection is made by spur gears with an outer vertical shaft

D, which drives shaft *E* mounted on the arm. Shaft *E*, in turn, rotates, through bevel gears, a vertical shaft at the rear of the head which drives the drill spindle. The spindle can be started, stopped or reversed by lever *F*, which controls the connection between shaft *E* and the rear vertical shaft. The head is traversed along the arm by handwheel *G* and the spindle can be fed by handwheel *H* or by power. The spindle can also be traversed rapidly up or down by pilot wheel *J* after the feed has been disengaged.

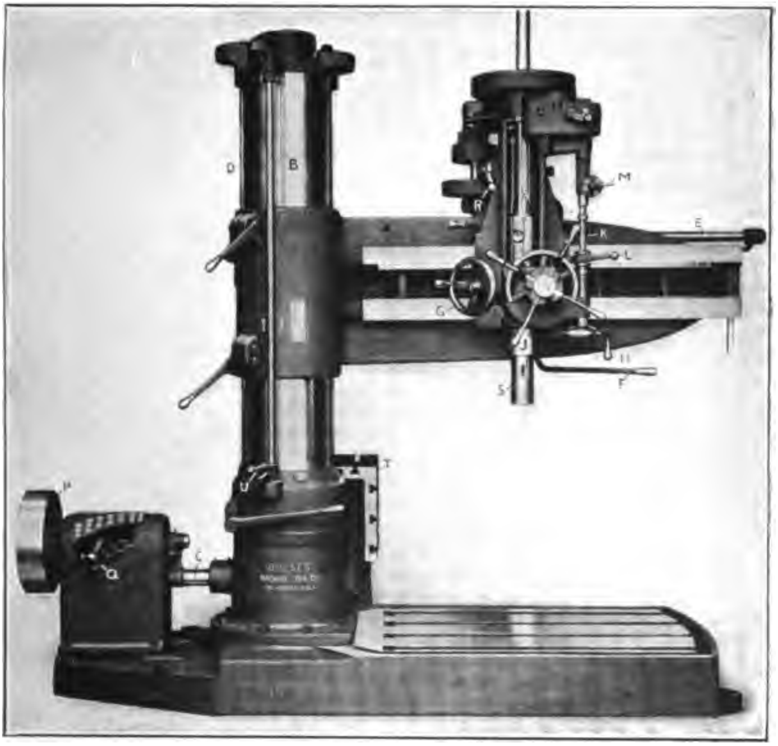


Fig. 1. Dreses Radial Drilling Machine

The power feed is derived from the spindle through gears which drive shaft *K* which rotates, through worm-gearing, a pinion shaft meshing with a rack cut in the spindle quill. The feed is engaged or disengaged by handle *L*, and it can also be disengaged by an automatic stop mechanism, which is adjustable and can be set previously for tripping the feed when a hole has been drilled to the required depth. The amount of feed is varied by handles *M* and *N*, which change the combination of the feed gearing enclosed at *O*. The spindle speeds are changed by shifting lever *Q* of the geared speed-box to different positions controlled by the notches shown, and the range of seven speeds obtained in this way can be tripled by back-gears in the spindle head, which are engaged or disengaged by handle *R*. The radial arm *A* can be adjusted vertically on column *B* by power, the adjustment being controlled by lever *U*. Both the arm and column can be clamped rigidly in any position by the levers shown. The work is placed either on table *T* or directly on the base, the position depending on its size.

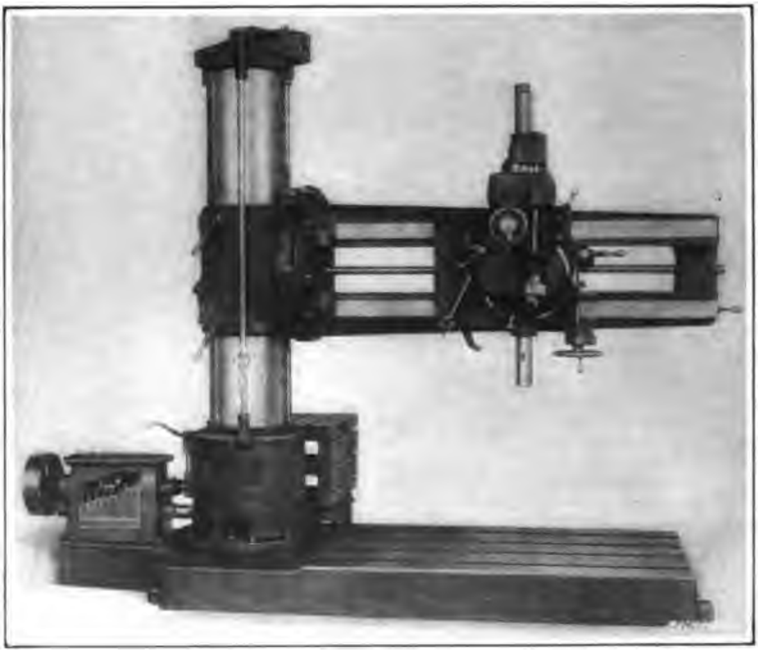


Fig. 2. Cincinnati-Bickford Full Universal Radial Drilling Machine

The plain radial type of drilling machine just described can only be used for drilling holes at right angles to the base. The universal radial drilling machine is adapted to the drilling of holes at an angle with the base. Such a machine is shown in

Fig. 2. The head and spindle of a "full universal" machine can be set at an angle with the radial arm, and the arm itself can also be rotated about its own center or axis, so that the drilling spindle can be placed in almost any position. With the exception of the changes necessary to permit these adjustments, the construction of the universal radial drill is practically the same as that of the plain type. The construction, of course, varies more or less according to the make of the machine, but the main features remain the same in all the different kinds manufactured.

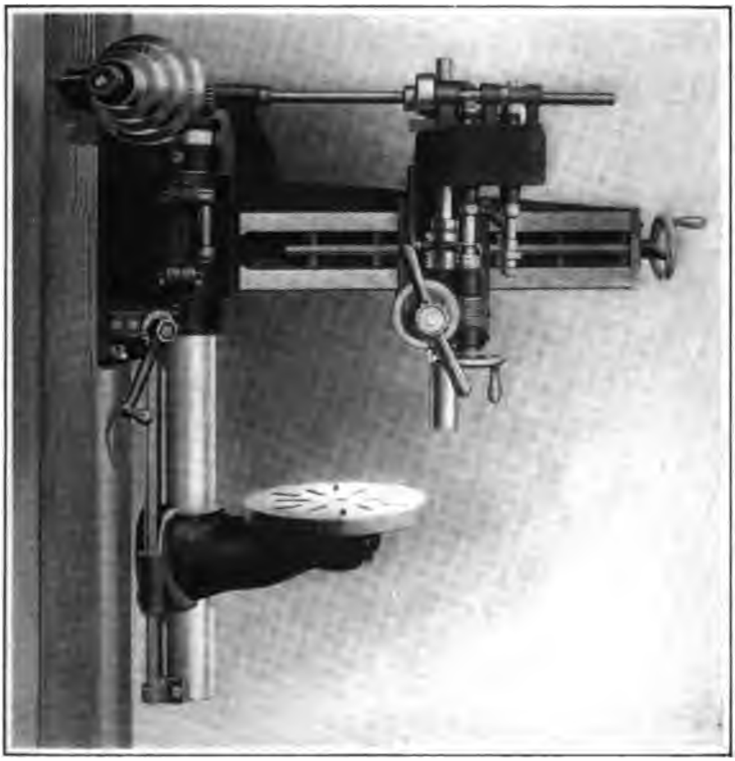


Fig. 3. Canedy-Otto Wall Type Radial Drilling Machine

In Fig. 3 is shown a machine known as a post or wall radial drill. It is, in principle, constructed along the same lines as a plain radial drilling machine, but is not provided with a base, it being adapted to be attached to a wall or post. It meets the requirements of shops where a radial drill is needed but where the cost of one of the standard type is too high, and is especially intended for use in smaller machine shops, garages, blacksmith shops and bridge and boiler shops where a wide range of drilling is done occasionally. The arm swings about a post in the same way as in the regular radial machine, and the head slides along the arm in a similar manner.

Multiple-spindle Drilling Machines. — A great many parts that have to be drilled require holes of different diameters, and other operations, such as counterboring, reaming, or countersinking, are frequently necessary. When work of this class is done in a machine having one spindle, considerable time is wasted in removing one drill and replacing it with a different size or with some other kind of tool. For this reason, drilling machines having several spindles are often used when the work requires a number of successive operations. The advantage of the multiple spindle or "gang" type is that all the different tools necessary can be inserted in the various spindles, and the drilling is done by passing the work from one spindle to the next. By this method, holes of different diameter can be drilled and counterboring or reaming operations performed without changing any tools. Multiple-spindle machines can also be used to advantage for other purposes.

One type of multiple-spindle drilling machine is illustrated in Fig. 4. This particular design has four spindles, but the number of spindles in a machine of this type depends on the work for which it is intended. The spindles are all driven from a horizontal shaft *S* at the rear to which they are connected by belts as shown. The idler pulleys *I*, over which the driving belts pass in making the quarter turn, can be adjusted for varying the tension of the belts by the handwheels *W*. The table *T* can be raised or lowered by the screw and crank shown, to suit the height of the work, and the spindle heads *H* also have vertical adjustment. The spindles are fed downward for drilling by the hand levers *L*.

The method of using a multiple-spindle machine for performing successive operations on the same part is illustrated in Fig. 5.

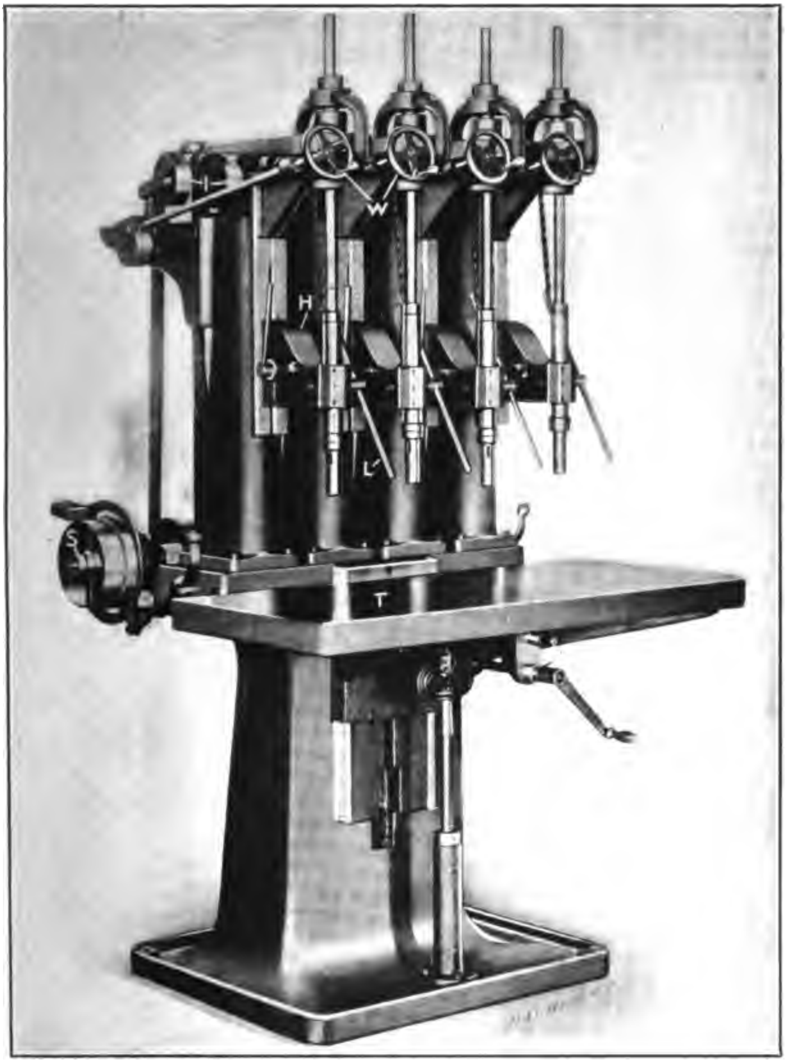


Fig. 4. Henry & Wright Multiple-spindle Drilling Machine

The work *W*, which is held in a box jig, is drilled and reamed at *a* and *b*, and a small hole *c* is drilled in the end. The holes *a* and *b* are first drilled with the left-hand spindle by feeding the drill through guide bushings *A* and *B*. The jig is then turned over (as shown by the dotted lines) and moved to the next spindle containing a reamer of the proper size, which is guided by bushings *D* and *E* in the bottom of the jig, as it is fed through the work. The third and last hole *c* is drilled by the right-hand spindle, while the jig is standing on end as shown. The advantage of having all the tools at hand, so that the work can be completed by simply moving it from one spindle to the next, is obvious.

Drilling machines of the multiple-spindle type are also commonly used for drilling a number of holes simultaneously. The arrangement of these machines is varied considerably to suit different kinds of work, but they may be divided into two general classes, namely, those having spindles which remain in the same plane, but can be adjusted for varying the center-to-center distance, and those having spindles which can be grouped in a circular, square, or irregular formation. The first class referred to is used for drilling rows of bolt or rivet holes in steel plates, etc., and the second type is adapted to the drilling of cylinder flanges, valve flanges or similar work.

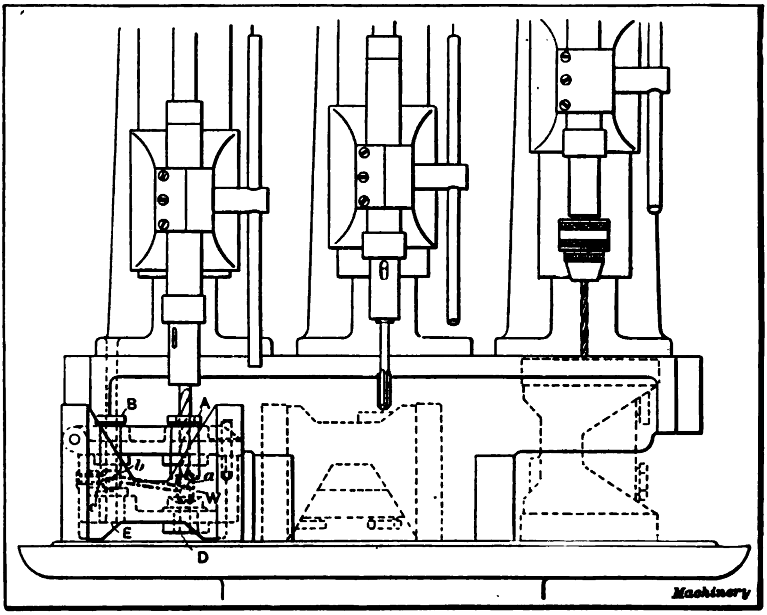


Fig. 5. Method of Using Multiple-spindle Machine for Successive Operations

In Fig. 6 is shown a multiple-spindle drill of the first of the two classes referred to, the spindles being arranged in the same plane, but capable of adjustment for various center distances. The machine is shown in operation, indicating the different center distances to which the spindles may be adjusted in this case. In this particular design, the spindles are driven by a double spiral gear drive, which has proved a quiet, efficient, and durable method for driving machines of this type. This method of drive also permits the spindles to be adjusted very closely together. The spiral gears are driven through a three-step cone, and with a two-speed countershaft this gives six changes of speed to the spindles. When these machines are used continuously on practically one class of work, it is better, however, to

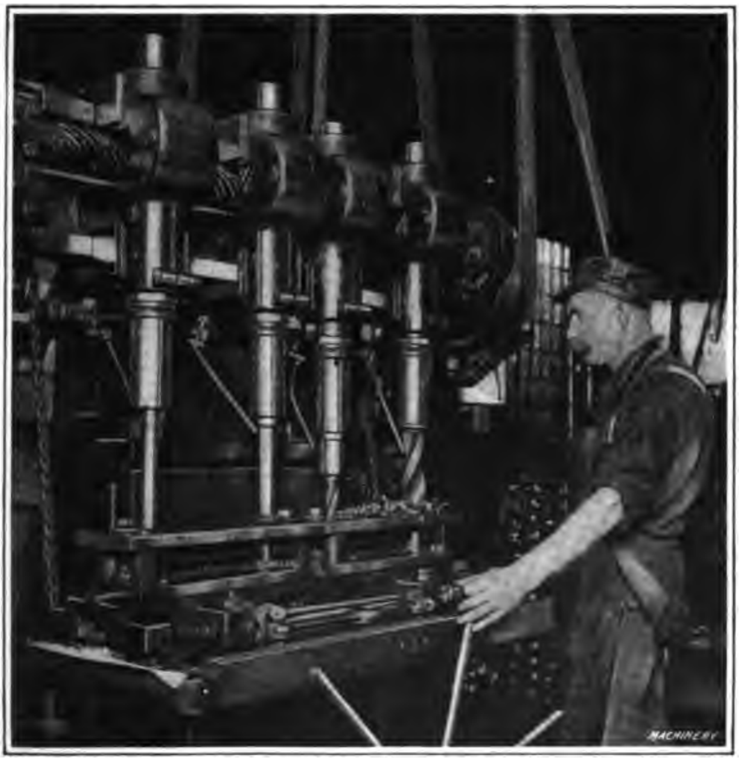


Fig. 6. Moline Tool Co.'s Multiple-spindle Drilling Machine

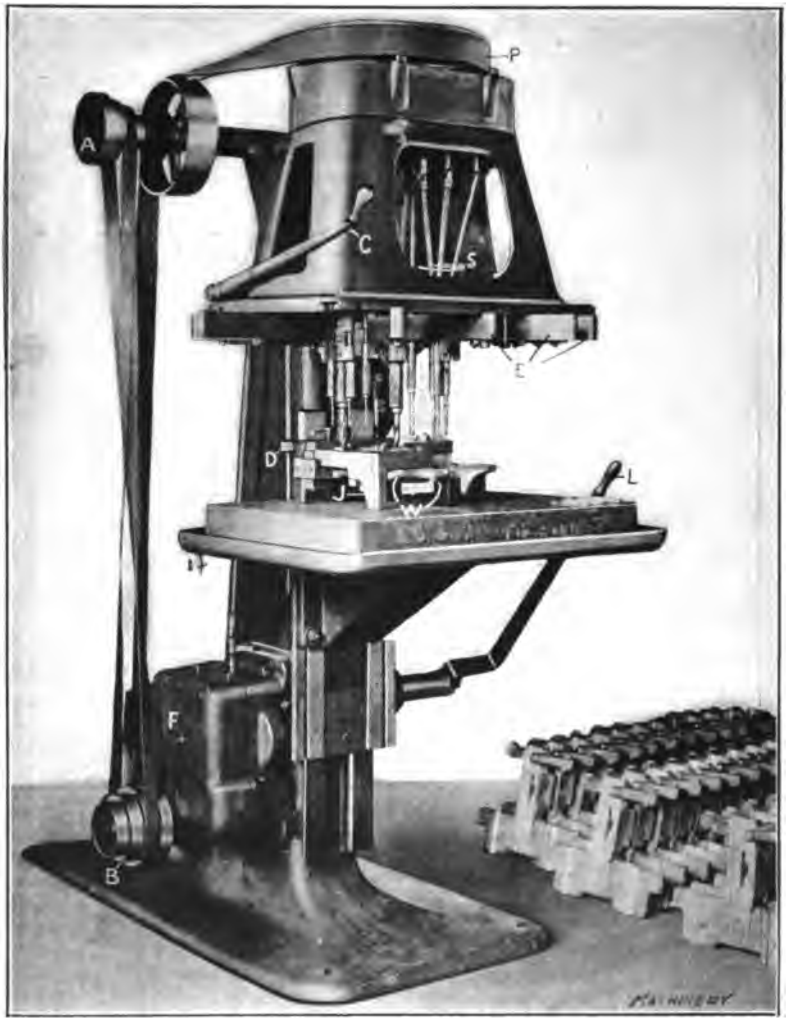


Fig. 7. Pratt & Whitney Adjustable Multiple-spindle Drilling Machine

use a single pulley drive, which, with a two-speed countershaft, will give two speeds. In this type of machine, the spindles are not fed into the work, but the work-table is fed upwards toward the spindles by means of the star wheel provided, which, through a worm and worm-gear and a pinion-and-rack feed, moves the table upward or downward. A power feed is also provided through pulleys at the left, which are not shown. There are a great number of different types of machines of this class, many of which vary to a considerable extent in arrangement, but which are used for the same classes of work.

A machine of the type in which the spindles may be grouped in a circular, square, or irregular formation is shown in Fig. 7. This machine has sixteen spindles, all or part of which can be used, as required. These spindles are driven from a single pulley *P* to which they are connected by shafts *S* and spur gears. The connecting-shafts have universal joints which permit the spindles to be arranged in accordance with the work. When the machine is in operation, the table and work are fed upward against the revolving drills. The feeding mechanism is located at *F* and the power feed is derived from pulleys *A* and *B*, which are connected by a belt as shown. The table can also be fed by hand lever *L*, which is connected with the feed pinion shaft. By simply loosening a nut, this lever can be set to the most convenient position for the operator. The power feed is engaged or disengaged by a downward or upward movement of lever *C*. It can also be disengaged automatically at any point by an adjustable stop *D*. As practically all work done on this type of machine is "jig drilled," the spindles are set by aligning them with the holes in the jig. The position of the spindles is changed by adjusting the spindle arms *E* which are clamped to the under side of the housing. The spindles have an independent vertical adjustment so that drills of different lengths can be used. This feature also permits setting the spindles for drilling holes that are not in the same horizontal plane. The machine illustrated is set up for drilling lathe carriages. The work *W* is mounted in a jig *J* and the various holes are all drilled at the same time. A number of castings which have been drilled are shown on the floor to the right.

Multiple-spindle machines of this type are also built in much larger sizes and in designs which are adapted to different classes of work.

Turret Drills. — A type of drill which may be said to be a combination of an upright and a multiple-spindle drilling machine is shown in Fig. 8 and is known as a six-spindle vertical turret drill. This machine has been designed to facilitate the performance of successive operations on work which must be drilled, reamed, counterbored, and tapped. With this machine, all of these operations can be performed at one setting of the work. The sliding head of the machine is balanced by a weight inside of the column. This head carries the feeding mechanism, the indexing locking mechanism, and the spur gearing for transmitting motion from the vertical driving shaft to the rotating spindles of the turret head. The six-spindle turret is mounted on the sliding head in such a manner that the turret is free to rotate on the head, so that any spindle may be swung into the working position without stopping the machine. The indexing is actuated by means of a small lever on the front of the

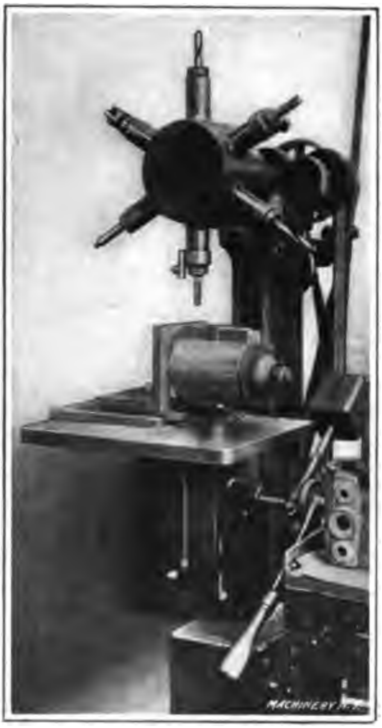


Fig. 8. Quint Vertical Turret Drill

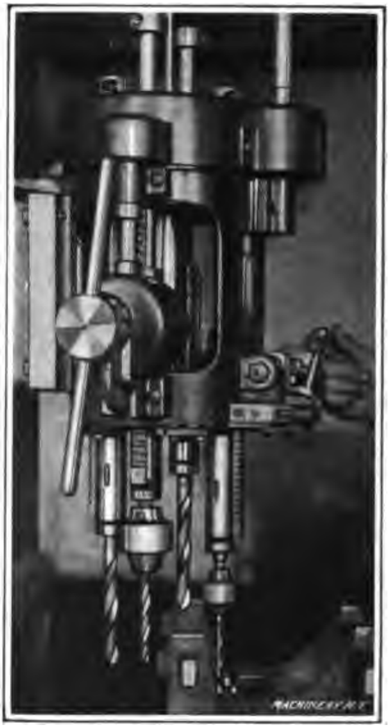


Fig. 9. Turner Turret Drilling Machine

turret. When this lever is swung to the right, it releases the index bolt; the turret is then rotated to bring the required spindle into the operating position, and the lever will then automatically lock the turret in place. The spindle which is in the operating position is the only one which revolves when the machine is operated, the other five spindles remaining at rest.

The advantages of a turret drill designed along the lines described are very apparent. The machine is simple in construction, and yet it permits of duplicate work being produced with great accuracy and rapidity. For certain classes of work, this type of machine has advantages over the regular multiple-spindle drilling machine. The work need not be moved from spindle to spindle, but the work, once located, is in position for the different spindles of the turret as one after the other is indexed around.

Another type of multiple-turret drilling machine is shown in Fig. 9. In this case the turret indexes around in a horizontal plane instead of in a vertical plane, as in the machine just described. Each spindle in the turret carries a different tool, which may be indexed to come into exactly the same position as the preceding tool. The turret rotates automatically, and when the operator returns the spindle to its full height, the turret indexes to bring the next spindle into the operating position. The spindles may be fed either by hand or by power. For the hand feed, either a handwheel or a lever is used, the former being more sensitive. The feed mechanism is driven from the vertical shaft which drives the spindle, and the feed may be engaged or disengaged without stopping the machine. An automatic trip is provided to throw out the feed at any predetermined point in the spindle travel. The turret drilling machines are especially useful when successive operations are to be performed on a piece of work that must be clamped in place on the drilling machine table, because it eliminates the time for resetting the work, or for the changing of the tools.

High-duty Drilling Machine. — Two views of a powerful and rigid drilling machine which is especially adapted to rapid drilling are shown in Fig. 10. This type was developed for driving modern high-speed drills, which are capable of much higher speeds than drills made of carbon steel. The frame of the machine is designed to avoid any deflection when subjected to heavy feeding pressures. Where there is any springing action, either in the frame or work-table, the drill will bind in the hole (especially if it be a long one) and this greatly increases the amount of power required. The increased friction also expands the drill, thus causing it to bind more tightly, which may result in breaking the drill, owing to excessive torsional strain.

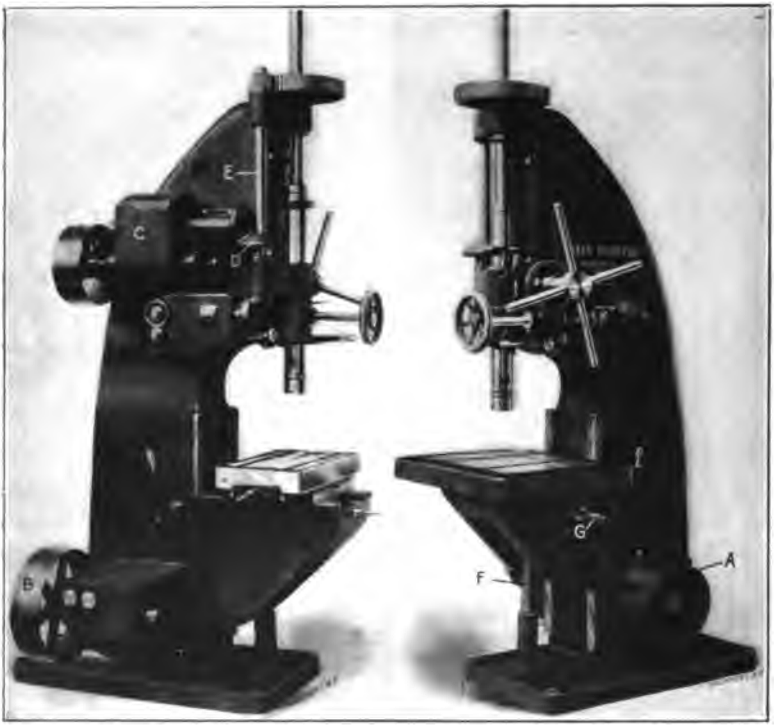


Fig. 10. Baker Bros. High-duty Type of Drilling Machine

This machine is driven by a belt operating on tight and loose pulleys at *A*. From here the motion is transmitted through enclosed back-gears to an intermediate pulley *B* on the other side of the machine, where connection is made by belt with speed-box *C*. There are eight speed changes obtained by sliding gears in this speed-box. Connection is made with the spindle through the bevel gears *D*, vertical shaft *E* and the spur gears shown. The illustration to the right shows the machine equipped with a plain work-table, and the left-hand view shows a "compound" table having longitudinal and cross adjustments. These tables have vertical adjustment on the face of the frame or column. This adjustment is effected by turning shaft *G* which operates elevating screw *F*. The compound table permits work to be accurately centered under the drill, after it is clamped in place.

The following figures will give a general idea of this machine's capacity for rapid drilling. Several $1\frac{1}{8}$-inch holes were drilled through $4\frac{1}{4}$-inch cast-iron blocks at the rate of $8\frac{2}{3}$ seconds per hole, and a number of $\frac{15}{16}$-inch holes were drilled through $\frac{3}{4}$-inch machine steel plate at the rate of $3\frac{1}{2}$ seconds per hole.

Sensitive Drill Presses. — The type of machine illustrated in Fig. 11 is intended especially for drilling small holes in light work. The power is transmitted directly to the spindle by belts which operate on the pulleys shown. This particular design is driven direct by a motor *M* which is connected with the lower cone pulley. The speed changes are obtained by shifting the belt connecting the two cone pulleys to steps of different diameter, and the tension of the belts can be varied by the hand-wheels *W*. The spindle and drill have a hand-feeding movement only. This is effected by hand lever *H*, which rotates a pinion meshing with a rack attached to the spindle quill. This simple method of feeding the drill has two distinct advantages when applied to the drilling of small holes: In the first place, it enables the workman to drill rapidly, because, ordinarily, little time is required for drilling small holes and the drill can be raised and lowered quickly when its movement is entirely controlled by hand. The hand-feed is also very sensitive, as the operator can tell by the sense of feeling about how much work the drill is doing, and by regulating the downward feeding pressure accordingly, the breaking of drills is largely avoided. For this reason, light machines of this class are called sensitive drills. The machine illustrated has two work-tables. The upper square table can be set at an angle with the spindle for angular drilling and for supporting work having an angular base. When this table is not in use it can be swung to one side. The round table beneath can be adjusted vertically on the column, and the position of the spindle head can also be varied as required. When necessary, the round table can be removed from its supporting bracket and be replaced with either the cone or crotch centers shown. These centers are used for supporting the ends of shafts, spherical and cylindrical parts, etc. This machine has a capacity for holes up to about $\frac{9}{16}$ inch in diameter.

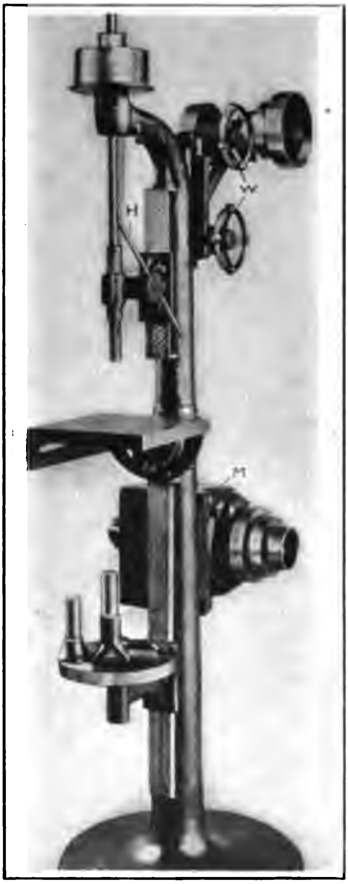


Fig. 11. Drill-press of the Sensitive Type

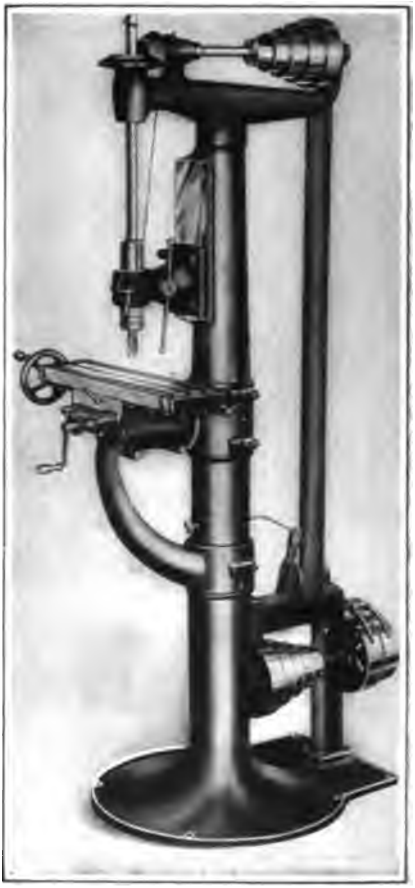


Fig. 12. Knight Milling and Drilling Machine

Another special drilling machine which comes under the head of a sensitive drill is shown in Fig. 12. This is a combined drilling and milling machine which is designed for performing a variety of both drilling and vertical milling work. The table is so mounted on its supporting bracket that it may be tilted to any desired angle, its angular position being indicated by graduations. It can also be swung about the column and is provided with both longitudinal and cross-feed movements. A drill plate is also provided which may be bolted to the solid table when the machine is used for plain drilling. A number of attachments are also provided with this machine, making it especially useful for laying off and drilling holes in dies, jigs, and templets, or for other work where accuracy as to the distance between holes is required. It can also be used to advantage for drilling holes in a surface which is not at right angles to the drill. The universal adjustment of the table, together with the attachments, makes the machine applicable to a large variety of work, and it is well adapted for tool-rooms or small repair shops, experimental shops, etc. Many other special designs of drilling machines are found on the market, but the types shown embody the general principles of all.

CHAPTER III

TAPPING AND TAPPING ATTACHMENTS

Holes which are to receive studs or bolts are usually threaded by the use of taps. The hole is first drilled slightly larger than the "root diameter" of the thread, by using a "tap drill," as indicated at *A*, Fig. 1. The hole is then threaded by screwing a tap into it, as at *B*, after which a stud or bolt is inserted as at *C*. For example, if a hole were to be tapped for a $\frac{3}{4}$-inch stud having a U. S. standard thread, it would first be drilled to a diameter of about $\frac{5}{8}$ inch, and a $\frac{3}{4}$-inch tap would then be used to cut the thread. The diameter of a tap drill — which is so called because it is followed by a tap — varies somewhat for U. S. standard and V-threads. It is important to use a tap drill of the proper size, for if the hole is drilled too small, an excessive amount of power will be required for tapping. On the other hand, if the tap drill is too large, the threads will not have sufficient depth. This important subject will be considered later.

When tapping is done on a small scale, the tap is commonly turned with a hand wrench, but when considerable tapping must be done, it is better to rotate the tap by power. There are many appliances for machine or power tapping, which differ considerably in their construction, but most of them operate on practically the same principle. Some tapping devices are in the form of attachments which can be applied to the spindle of a regular drilling machine, the function of the attachment being to reverse the rotation of the tap for backing it out of the hole when the latter is tapped. Drilling machines are also built which have a tapping attachment for reversing the rotation of the spindle, the attachment being embodied in the design of the machine. There are also machines designed especially for tapping.

Taps. — The taps used for hand-tapping operations are usually made in sets of three, and are known as taper, plug, and bottoming taps. The point of the taper tap is turned down to the diameter at the bottom of the thread for a length of three or four threads and then several threads are chamfered or tapered. The rest of the tap is cylindrical. On the plug tap, three threads are chamfered or tapered at the point, whereas, on the bottoming tap, only about one thread is chamfered, so that the end of the latter has practically no taper. When tapping holes which extend through the part being tapped, it is common practice to simply run the taper tap clear through the piece, but when the tapped hole is comparatively deep and especially if the material is hard or tough, the taper and plug taps are frequently used alternately; for instance, if the taper tap begins to stick after being screwed down into the hole, then the plug tap is inserted to relieve the long cut made by the taper end of the first tap. When a hole is "blind" or closed at the bottom, and it is desired to tap as near to the bottom as possible, the taper and plug taps are followed by the bottoming tap, which, because of its short chamfer at the end, will cut a thread practically to the bottom of the hole.

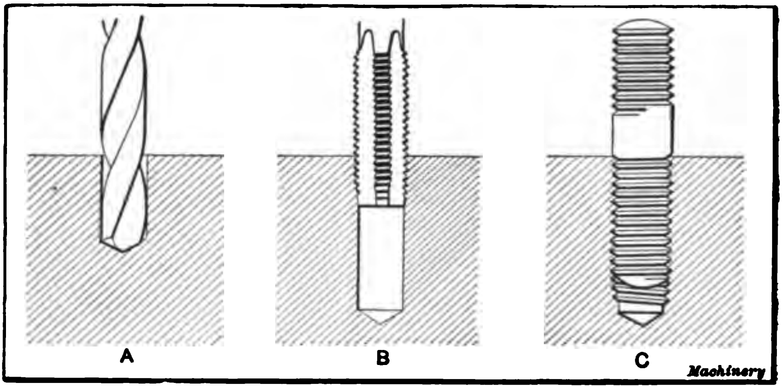


Fig. 1. (A) Tap Drill. (B) Tap for Threading Hole. (C) Stud inserted in Threaded Hole

Hand Tapping. — When tapping by hand, if the tapped hole must be square with a finished surface, care must be taken when starting the tap to see that it stands perpendicular to this surface. A double-ended form of tap wrench or one having two handles should be used if there is room, and care should be taken to press evenly on both handles, especially when starting the tap, to prevent it from being started at an angle. After the tap has been screwed in a short distance, its position can be tested by using a small try-square. Another method of insuring accurately tapped holes is illustrated in Fig. 2. As will be seen, a special tapping jig is used. This jig is clamped upon the surface of the work and has a vertical hole extending through it into which the tap shank fits. The jig is aligned with the hole to be tapped by means of a plug, as indicated at *A*; then, after the jig is clamped in this position, the bushing is removed, the tap inserted, the bushing replaced, and the tap screwed down through the work while the jig holds it in alignment.

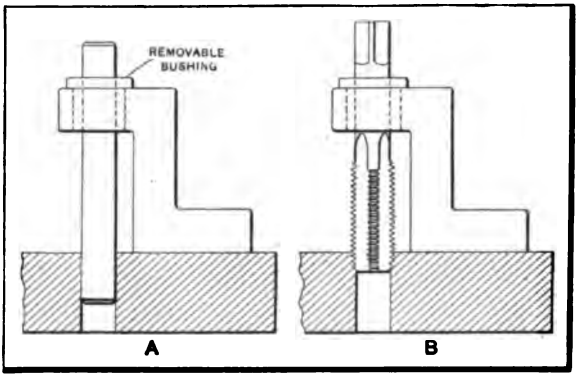


Fig. 2. Simple Tapping Jig

Sometimes the spindle of a drilling machine is used for guiding a tap. The method is to first drill the hole into the work, the latter being clamped to the table of the machine. The drill is then removed and a center similar to a lathe center is inserted in the drill-press spindle. This center is then engaged with the center hole in the end of the tap shank, and as the tap is screwed down into the hole with a wrench, it is steadied by feeding the drill spindle and center downward, thus holding it in line with the hole being tapped.

In ordinary shop practice hand tapping has been commonly used, but in recent years, with the improved tapping machines, tapping attachments, and collapsible taps, power tapping has in many instances taken the place of the hand tapping method. Of course, in some cases it is impossible to do anything else but tap a hole by hand. The great disadvantage of tapping by hand is the time consumed. While cutting a thread with a tap is not a difficult job, it requires care in the manipulation. When tapping by power one tap is all that is necessary.

Friction Tap- and Drill-holder. — Many tapped holes do not extend clear through the work, but are "blind"; hence, when the tap is driven by power, provision should be made for allowing the tap to stop in case it should strike the bottom of the hole, as otherwise it might be broken. Taps are also broken frequently because the drilled holes are not large enough, the result being that the strain on the tap becomes excessive, and breakage occurs unless provision is made for limiting the amount of driving power. One method of safeguarding the tap is to hold it in a friction chuck or holder, which will slip in case the tap strikes the bottom of the hole or meets with excessive resistance to rotation. A safety tap- and drill-holder is shown in Fig. 3. This holder has a shank *S* which is inserted in the spindle of the drill press, and at the lower end of this shank there is an enlarged part *A*, which is recessed to receive the friction socket *B*. This socket is held in place by a cap *C* which is screwed onto the enlarged part. Fiber washers *w* are placed on each side of the friction socket flange, and the cap *C* is tightened until the friction between parts *A* and *B* is sufficient to drive the tap. The check-nut *D* is then screwed against cap *C*, which locks the parts securely.

The tap itself is held in a socket *E*, which is inserted in the friction socket *B*. This tap socket is driven by the dovetailed keys *k*, which engage the keyways k_1, and is kept from dropping out of the friction socket, when there is no upward pressure, by a small spring-pin *m* which enters the groove m_1. The tap, which has a special shank, is also driven by side keys and is retained by a spring-pin *n* which engages the annular groove shown. The tap is not held rigidly but is allowed a slight "floating" movement to secure better alignment with the hole and a more perfect thread. If a tap which is held in a holder of this type strikes the bottom of the hole, the friction socket *B* will slip (provided the friction is properly adjusted) and the tap will stop turning while the shank *S* continues to revolve. In this way the breaking of taps is avoided.

This form of holder is also used for drilling, the drill being held in a socket *F* having a standard taper hole for receiving the drill shank. These sockets are also inserted in the friction socket *B* and are made in sets to receive drill shanks of different sizes. The power required to overcome the friction between parts *A* and *B*, causing a slipping movement, should be less than that represented by the breaking strength of the drill or tap. There are a number of different forms of friction tap- and drill-holders on the market. These operate on the same general principle but differ as to the method of obtaining and varying the frictional resistance. On some drilling machines an adjustable friction is introduced in the spindle-driving mechanism to prevent the breaking of taps.

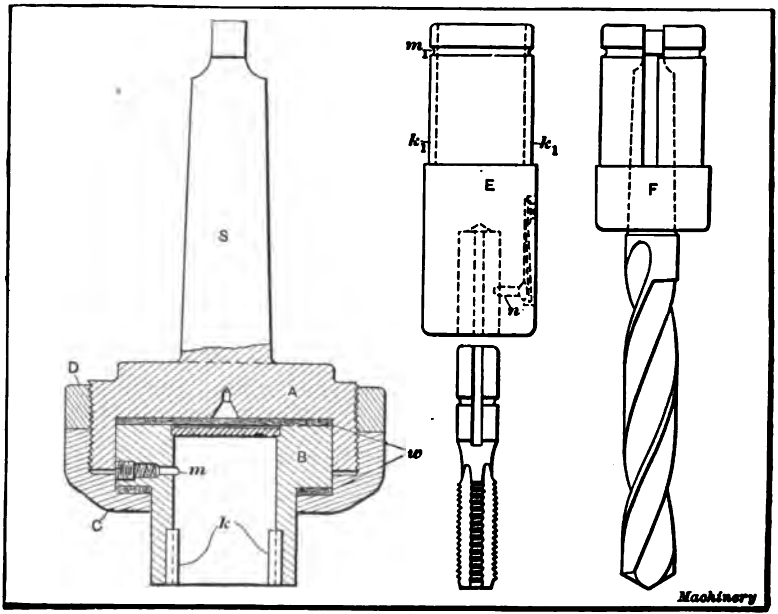


Fig. 3. Beaman & Smith Safety Drill- and Tap-holder

Automatic Reverse Tapping Chuck. — When tapping by power, the tap ordinarily is fed down into the hole to the required depth and its rotation is then reversed for screwing it out of the hole. There are different methods of obtaining this reverse motion. When the tapping is done in an ordinary drilling machine, special tap chucks are frequently used, which are designed to reverse the rotation of the tap when the latter has reached the required depth.

The Errington tapping device, shown in Fig. 4, is so arranged that the tap automatically stops when it strikes the bottom of the hole or when the adjustable depth gage *G* comes against the top of the work. The raising of the spindle then reverses the tap which backs out at an increased speed. This tapping chuck *C* is inserted in the spindle of a drilling machine just like an ordinary drill chuck. As the tap is automatically reversed when the spindle is raised, no reversing gears or double belts are required to stop or change the rotation of the machine spindle. When this chuck is used in connection with light duplicate work which will center itself with the tap, very rapid production can be obtained by the following method: The work *W* to be tapped is prevented from rotating by passing it between two parallel pieces *S* clamped to the drill-press table, just far enough apart to allow the work to be inserted easily. When a hole is being tapped, the spindle is raised and lowered with the right hand while the work is inserted between the parallel pieces with the left hand, the operation being practically continuous. When this method is employed, the drilling is first completed and then the parts are re-handled for the tapping operation. Small round or irregularly shaped parts can often be held to advantage in a special holder which is passed between guides *S* attached to the table. This particular make of chuck is provided either with a positive drive or with an adjustable friction drive that prevents the breaking of taps. Part of the chuck and gage *G* are prevented from rotating by a rod *R* which, in this case, rests against the left side of the machine column. This rod slides freely up and down as the spindle and tap are raised and lowered.

Friction-reducing Tapping Chuck. — Fig. 5 shows a Cincinnati-Bickford tapping chuck designed to facilitate the operation of tapping in horizontal, upright, or radial drilling machines. The special feature of this chuck is that a sleeve is provided driven by two ball-bearing keys. The quill or central portion of the chuck has on its upper face two lugs placed opposite each other, to which power is imparted from corresponding slots in the machine spindle. The quill is surrounded by a sliding sleeve, to the lower end of which is attached the tap-holder proper. The tap-holder is provided with a cylindrical hole for the shank of the tap, a square hole for its square, and a headless set-screw for holding the tap in place. Attached to the sides of the quill are two ball-bearing keys the purpose of which is to reduce to a minimum all frictional resistance when the tap enters the work and pulls the sleeve downward.

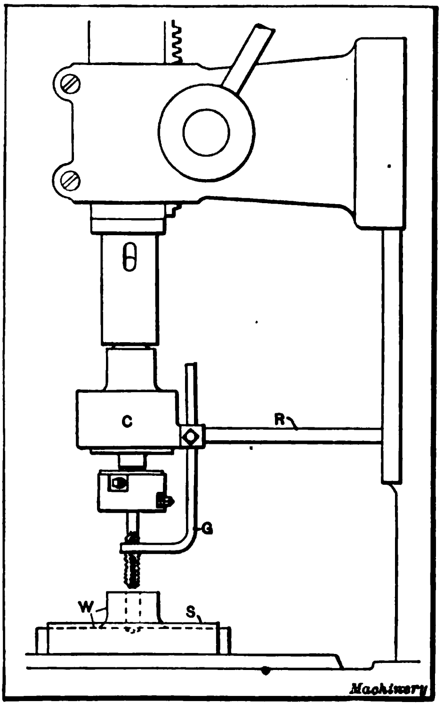


Fig. 4. Errington Automatic-reverse Tapping Chuck

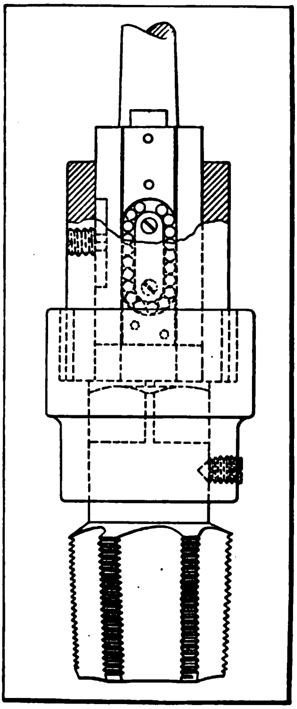


Fig. 5. Cincinnati-Bickford Tapping Chuck

Much of the power used when tapping with the larger sizes of pipe taps is due to the resistance of the machine spindle against sliding when under heavy duty. The pressure on the key is so great that it neutralizes the natural tendency for the revolving tap to enter the hole, and the spindle must be forced forward or a stripped thread will be the result. In the chuck shown in Fig. 5, the sleeve with ball-bearing keys will slide in exact accordance with the pitch of the thread, and all that the operator needs to do is to exert a slight pressure at the moment the tap comes in contact with the work, and, when it has entered to the required depth, reverse the spindle. The chuck affords a convenient means for holding taps, which economizes power and avoids the stripping of threads, thereby eliminating the need for a positive lead mechanism, and permits the driving of taps much larger than could otherwise be used in a machine of a given capacity.

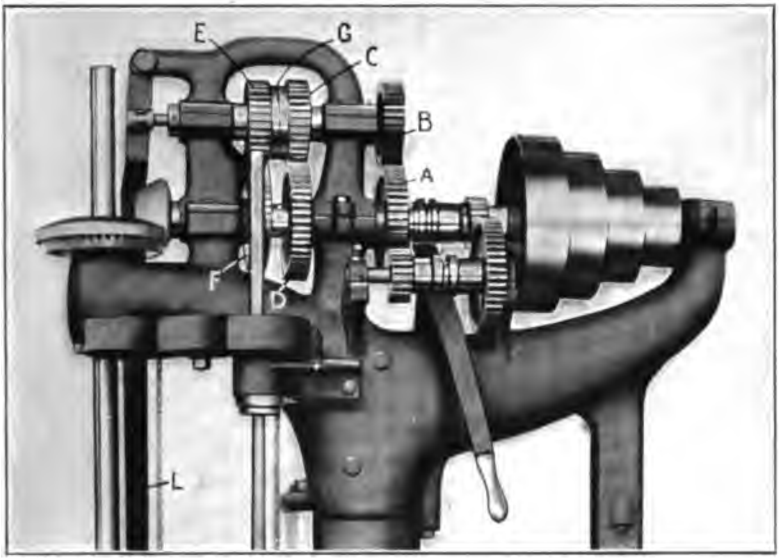


Fig. 6. Hamilton Tapping Attachment

Tapping Attachments. — Some drilling machines are equipped with special gearing which can be utilized for reversing the rotation of the spindle when tapping, so that a special reversing tap chuck is not necessary. This mechanism for reversing the spindle when the tap has reached the required depth is known as a tapping attachment. One form of tapping attachment is illustrated in Fig. 6, which is a partial view of an upright drilling machine. When a hole is being tapped, power is transmitted to the spindle through gears *A*, *B*, *C*, and *D*, until the tap has been fed to the required depth; the spindle rotation is then reversed by shifting lever *L*, which, by means of a friction clutch at *G*, engages gear *E* with *F* through an intermediate gear at the rear, which reverses the movement for backing the tap out of the hole. By placing lever *L* in a central or "neutral" position, the spindle can also be stopped, so that the machine is controlled by this single lever. Before beginning to tap, the feed-worm is disengaged and the tap is started in the hole by feeding it down with the hand lever. As soon as a thread is started, the spindle, being

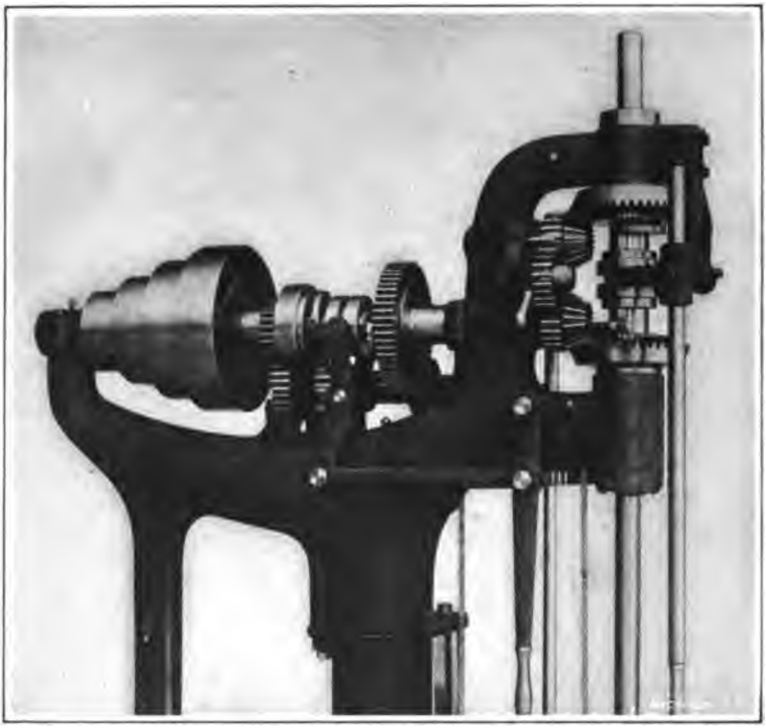


Fig. 7. Cincinnati-Bickford Tapping Attachment

free to move vertically, is fed down by the screwing action of the tap.

Tapping attachments on different makes of drilling machines differ, of course, as to their general arrangement. The Cincinnati-Bickford tapping attachment is shown in Fig. 7. This tapping attachment, in conjunction with the friction back-gear used on the machine, makes it possible to drill at a fast speed, tap at a reduced speed, and, after the spindle has been reversed, to withdraw the tap at four, or more, times the speed employed while tapping. Referring first to the friction back-gear, the object of this device is to eliminate the necessity for shifting the belt or stopping the machine in changing from high to low speed, or *vice versa*. When back-gears cannot be engaged without doing this, it is usually more convenient to perform the high-speed operations at a speed suitable for the low-speed tools. By a convenient arrangement of the back-gear mechanism, however, the operator can change instantly from the speed selected for drilling to one suitable for tapping, counterboring, or facing. The lever which controls these changes in speed is within easy reach of the front of the table and supplies a convenient means for starting or stopping the spindle to change tools.

The forward motion of the tapping attachment, shown to the right in the illustration, is derived from the lower bevel gear, while the reverse is obtained through an intermediate spur gear mounted on a sector, so that it and the gears it drives may be disengaged when not required for tapping. The device acts through friction clutches and, hence, operates quietly, the friction rings being expanded by hardened steel wedges which are adjustable for wear. The handle for engaging the wedge is at the front of the head, as indicated, and slides lengthwise to suit the height of the operator. The spindle starts backward at the same speed as it is driven forward, but as soon as the tap frees itself, the speed may be greatly accelerated by a pull on the friction back-gear lever, by throwing in the higher reversing speed.

Tapping Machines. — Machines designed especially for tapping or for drilling and tapping holes are made in quite a variety of designs. Some of these machines are intended for one class of work like the tapping of nuts, whereas others are adapted to tapping operations of a general nature; there are vertical and horizontal, and single- and multiple-spindle types.

A Garvin tapping machine of the vertical single-spindle type is shown in Fig. 8. The spindle is fitted with two friction pulleys *A* and *B* which are driven in opposite directions by one continuous belt. Between these two pulleys there is a double-faced friction clutch keyed to the spindle. This friction clutch is connected with lever *C* by a toggle mechanism, and an adjustment is provided for varying the tension of the clutch, thus providing a safety device to prevent the breaking of taps. The tap is started by lever *C* and is tripped and reversed automatically at any point by an adjustable screw-stop which strikes the tripping lever on the top of the machine. The spindle is counterbalanced so that after starting the tap the operation is performed automatically. The adjustable screw-stop which controls the tripping and backing out of the tap is at the upper end of the spindle. The pulley *B* for the reverse or backing-out movement

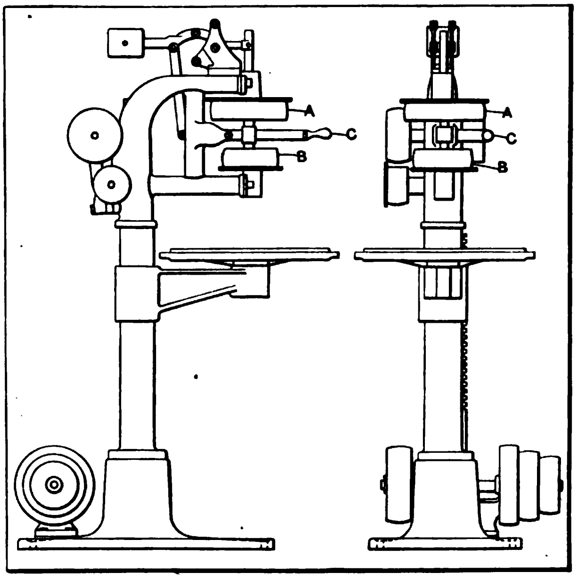


Fig. 8. Garvin Tapping Machine

is smaller than the other pulley, thus giving an increased speed. When designing fixtures for holding work to be tapped, care should be taken to so locate the supporting feet that the pressure of tapping will not cause any tilting action.

A vertical-spindle Rickert-Shafer tapping machine equipped with a friction drive is shown in Fig. 9. The spindle on which the friction disk *D* is mounted is shown at *A*, and this spindle also carries the operating bracket *B* on which a pinion is mounted that raises and lowers the tapping spindle. The friction disk spindle also carries an adjustable compensating spring *C* that holds the friction disk in the neutral position when the machine is not in use. The tapping spindle is connected to a counterweight *W* which is sufficiently heavy to withdraw the tap from

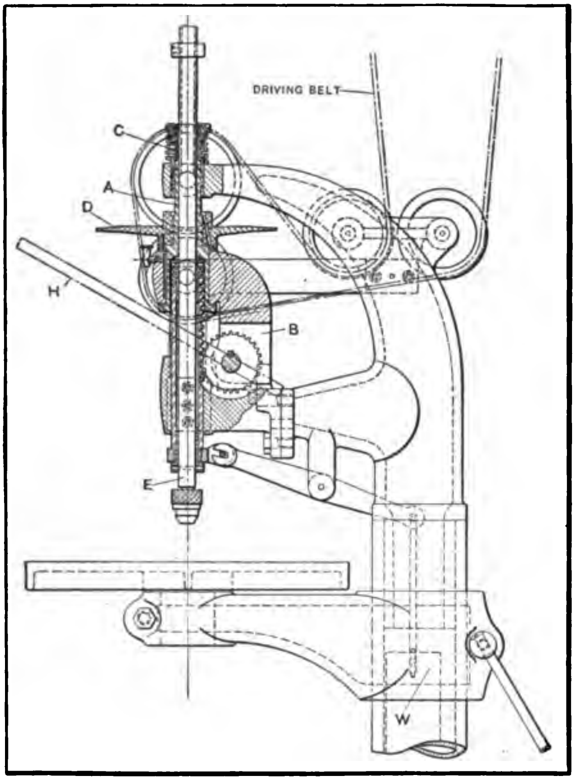


Fig. 9. Rickert-Shafer Tapping Machine

the work and lift the spindle to its highest position, leaving the operator's left hand free to reach for the next piece of work. On this machine the friction disk is brought into contact with the driving friction by a slight downward pressure on the hand lever *H*. A downward pull on this lever first raises bracket *B* and disk *D* against the driving friction, and then lowers spindle *E*. An upward movement of *H* lowers *B* and engages disk *D* with the reversing friction, thus backing the tap out of the hole.

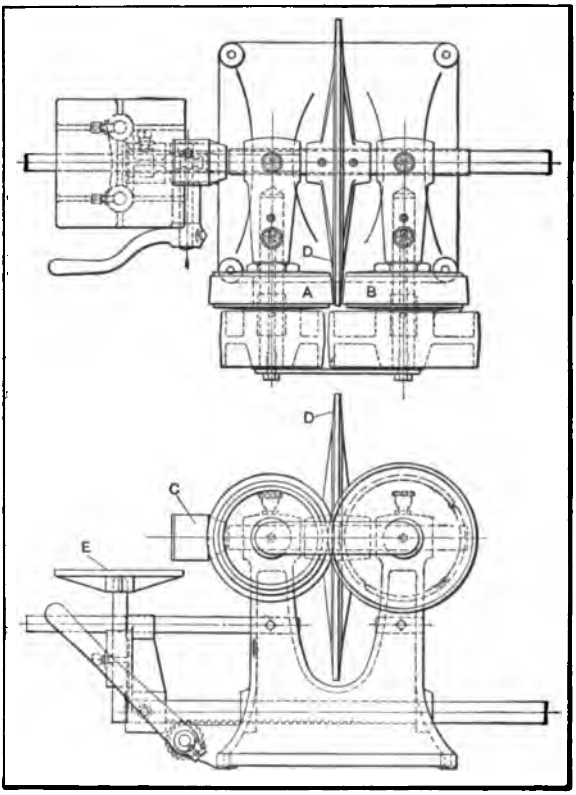


Fig. 10. Horizontal Tapping Machine

It will be seen that the machine is driven by a single belt which runs around the pulleys that drive the forward and reverse frictions in the manner shown. The two pulleys rotate in the same direction and the reversal of the tap is due to the fact that the friction disk comes into contact with the opposite sides of the forward and reverse frictions.

A small Rickert-Shafer horizontal tapping machine is shown in Fig. 10. The drive is of the friction type, the mechanism consisting of a metallic disk *D* mounted between two friction driving wheels *A* and *B*. The disk is of aluminum and the driving wheels of friction board. By moving the work forward, the disk is thrown against the rear or tapping friction, while pulling the work backward brings the disk into contact with the forward or reverse friction wheel. The tap is held in chuck *C* and the work on the table *E*, which latter is equipped with a lever and rack-and-pinion feed. The machine is driven by a single belt which comes down around the rear or tapping friction-wheel pulley and then up around the front or reverse friction-wheel pulley. It will be evident that both of the friction wheels rotate in the same direction, and the reversal of the tap is due to the fact that the disk engages the friction wheels on opposite sides.

There is also a horizontal type of tapping machine of single-spindle design which is equipped with two driving pulleys, one being the reverse pulley and the other for the forward drive. Interposed between these two pulleys there is a positive clutch. When the machine is in use, the work is held on the pad attached to the tailstock spindle and preferably in a socket fixture. At the rear end of the tailstock spindle there is an adjustable stop which controls the depth to which the hole is tapped. This stop disengages the clutch between the driving pulleys, and the tap remains stationary until the reverse motion of the feed lever draws the clutch into engagement with the reverse pulley, thus backing the tap out of the hole.

Drilling and Tapping Machine. — A Barnes drilling and tapping machine is shown in Fig. 11. This machine can be set so that when the tap reaches the depth required the spindle will automatically reverse, backing the tap out at an increased speed. It can also be arranged so that when tripped either automatically or by hand the driving clutch will be thrown to the neutral position, thus stopping the spindle instead of reversing it. The machine is driven from belt pulley *A* which transmits motion to the spindle through gearing that enables eight changes of speeds to be obtained. There are also eight feed variations. On driving shaft *B* two bevel gears are mounted which mesh with gears on the inclined shaft *C*. The reverse motion of the spindle is effected by clutches interposed between the gears on *B* which serve to lock one or the other of these gears to the shaft. Lever *D* through a connecting-bar and bellcrank controls the

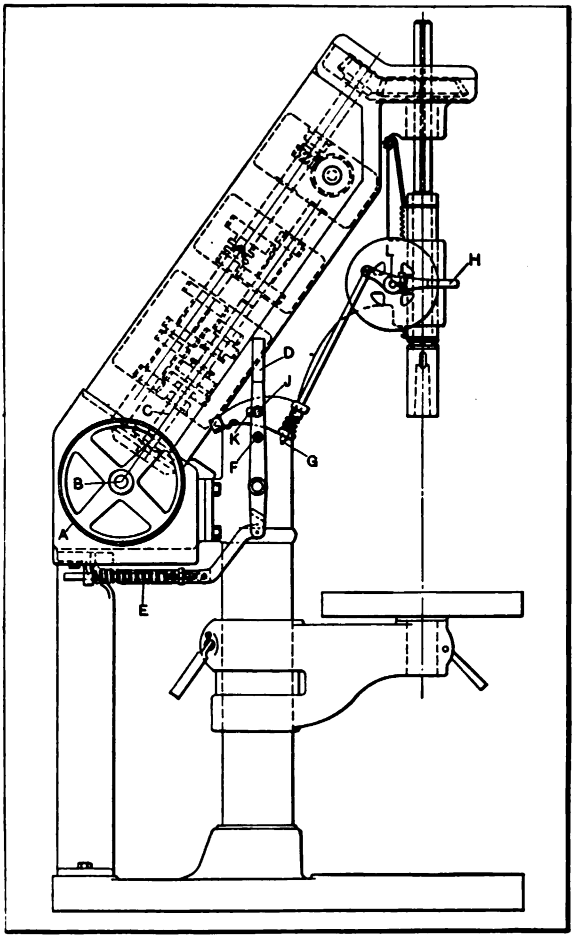


Fig. 11. Barnes Drill Co. Drilling and Tapping Machine

position of the clutches on the driving shafts; thus, when lever *D* is in a vertical position the clutches are not engaged with either driving gear and the shaft runs idle, this being a neutral position. When lever *D* is pulled forward against the action of spring *E*, pin *F* latches on bar *G*, thus holding lever *D* in the forward position. The spindle is then rotated in the direction for tapping until rod *G* is raised; then lever *D* flies back and causes the main spindle to be reversed unless pull-pin *J* is pushed in so as to engage stop *K*, in which case the backward movement of lever *D* is arrested at the neutral position and the spindle stops. This tripping of lever *D* by the action of rod *G* may be controlled either by hand or automatically. The hand control is effected by lever *H* and the automatic control by adjusting the threaded clamp nut *L* so as to trip the spindle at any point within its range of travel. The reversing speed of the spindle is 1¾ times faster than the forward or tapping speed. The clutches for the forward and reverse movements are of the friction type and may be adjusted by means of a screw and jamb-nut in the expanding rings so as to transmit the required amount of driving power.

Semi-automatic Nut Tapper. — A six-spindle Acme semi-automatic nut tapping machine is illustrated in Fig. 12. This particular machine has a capacity for tapping either square or hexagonal nuts having tapped holes varying from ⅝ to 1 inch in diameter. Each spindle is operated independently and is counterweighted to prevent the breakage of taps. The spindles are provided with an automatic lifting device consisting of a worm and auxiliary mechanism which is located at the top of the machine. By means of this device the spindle and tap are lifted after one nut has been tapped, allowing the next nut to be fed in automatically to the nut-holder from an inclined chute. These chutes may be seen in the illustration, being located just in front of each spindle. As the tap passes through the nut, the worm at the top of the spindle drops, and, in so doing, comes into contact with a bronze washer or collar. This collar, through a bellcrank arrangement of levers, pushes a chute into contact with the threads of the worm, whereupon the latter rises and lifts up the tap and the nuts on it clear of the nut-holder, allowing another nut to be fed in. This feeding movement is effected by a finger operated by a rod at the rear of the machine through a system of levers which come into action as the spindle is lifted. The cycle of operations referred to is repeated until the shank of the tap is filled with nuts, whereupon the tapping spindle ceases to operate because the filled tap prevents the worm from contacting with the bronze collar previously mentioned. As soon as the tapping spindle ceases working, the operator removes the filled tap by depressing a foot lever (not shown in the illustration); this lifts the spindle and tap clear of the nut-holder, enabling the tap to be easily removed. The spindles are equipped with quick-acting ring chucks so that the tap can be removed while the spindle is rotating. The nuts are then slipped off the

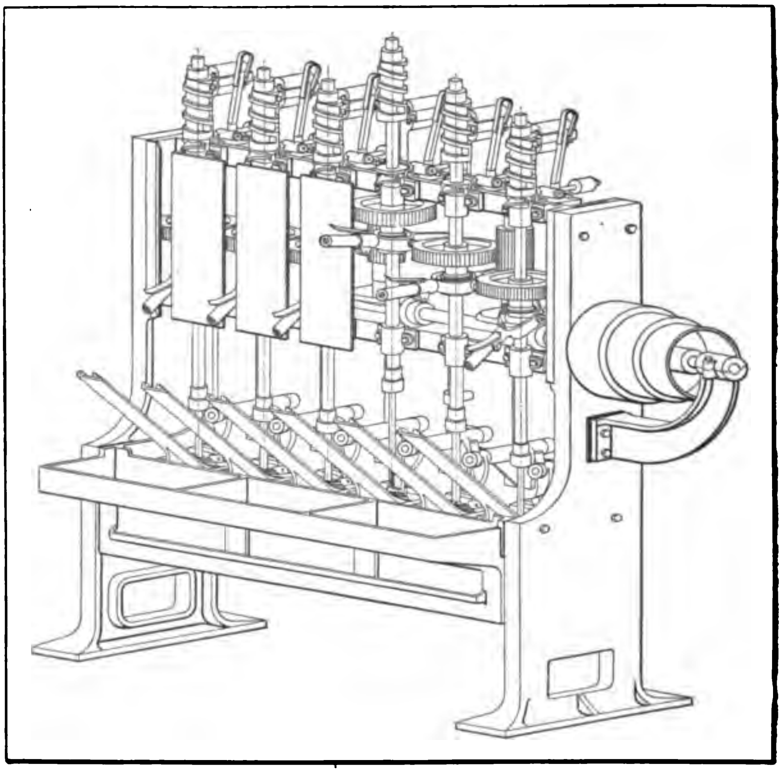


Fig. 12. Acme Semi-automatic Nut Tapping Machine

shank of the tap, the latter is replaced in the chuck, and, when the operator removes his foot from the foot lever, the machine begins operating again. The worm cannot drop until the threads on the tap have cleared the nut, so that, if the trips on the machine are properly set, it is impossible for two nuts to be on the threaded portion of a tap at the same time. The feed chute for the nuts and also the nut-holder can be adjusted to suit various sizes within the range of the machine. Lubricant is supplied to the taps by a rotary oil pump.

Automatic Nut Tapper. — Many attempts have been made to design automatic machines for tapping nuts, that would operate continuously. Many of these, however, have not proved satisfactory. One of these automatic machines which has proved efficient is equipped with a tap having a shank that is bent on a rather large radius so that the extreme end is at right angles to the main tap body. This shank with the right-angle bend is held in a groove in the spindle large enough to allow the nuts to slide over the shank. When the machine is in operation, the tapped nuts are forced along the shank around the curved end and ejected from an opening in the side of the spindle. The reason for using a bent tap is that the curved shank makes it possible to drive the tap and at the same time have it sufficiently free in the spindle opening to allow the nuts to pass over the shank and be ejected at the end; consequently the machine can be operated continuously and without reversing the spindle or removing the tap for unloading the tapped nuts.

The nut blanks are delivered from the hopper to the feed chute by means of a vane feed, and gravity carries the blanks down into position against the plunger or "starter" which starts them onto the tap. There are four of these feed vanes which are enclosed in a central case, so that the pressure or weight of the blanks in the hopper cannot interfere with their operation. These vanes are rotated by a ratchet and pawl, which derive their motion from the main driving shaft. The ratchet is held between friction flanges so that in case scrap metal or a thin nut blank tends to wedge in the nut groove and retard the progress of the feed vanes, the ratchet merely slips, and damage to the mechanism is avoided.

The tap spindle and the plunger, or starter, which transfers the blanks from the bottom of the chute to the tap, are inclined at an angle; and the blanks come out of the feed chute at a like angle, thus causing each blank to leave the chute in the proper position to be engaged by the plunger and started onto the tap. The tap spindle has a slight lateral travel and is counterbalanced, giving the spindle practically the equivalent of a floating movement; after the starter has fed the blank part way onto the tap, the spindle descends during the completion of the tapping operation, thus keeping the blank stationary while it is being tapped, instead of pulling it through the nut-holder or guides.

Diameter of Tap Drill. — Tapping troubles are often caused by using tap drills that are too small in diameter. For ordinary manufacturing, not more than 75 or 80 per cent of the standard thread depth is necessary, and for some classes of work not more than 50 per cent is required. Tap drill sizes, especially for machine screws, should be varied according to the material to be tapped and the depth of the tapped hole. When a tap breaks or anything goes wrong in connection with its work, it is probably the most natural thing in the world to blame the tap maker. In many cases, however, the trouble is due entirely to the conditions under which the tap is working.

Tap manufacturers often find that users of taps actually punch or drill the holes to be tapped of a smaller diameter than the root diameter of the thread, so that the end of the tap must act as a reamer before the thread can be cut. In this case the tap becomes a taper reamer, reaming a tapering entrance to the hole. Frequently the tap will refuse to "catch the thread" at all and will ream clear through the nut. Should the thread happen to "catch" after reaming part way, however, a short, weak thread results. This condition evidently requires considerable power, and explains why taps frequently break as soon as they begin to cut. When it is remembered that generally not more than 80 per cent of the standard thread depth is necessary in ordinary manufacturing work, and that in many cases not more than 50 per cent is required, it is apparent how useless it is to have the holes too small, and, in most cases, to even attempt to secure a full thread.

Tap drill sizes for machine screws, in particular, should be varied according to the material to be tapped and the depth of the tapped hole. In general, for holes where the screws enter more than one and one-half times the diameter, one-half of the full thread is usually sufficient, according to the experience of the Wells Brothers Co. Soft, tough materials, such as copper, Norway iron, drawn aluminum, etc., should have a larger hole for the tap than the hard, crystalline materials, such as cast metals. The reason for this is that otherwise the taps of the threads of the softer materials will be torn off, thus actually decreasing the effective depth of the thread of the tapped hole as compared to what it would be had the hole originally been drilled larger. On the other hand, if the hole is originally drilled large, the tap will, when cutting tenacious materials, especially after the keen edge has been slightly dulled by use, reduce the size of the hole by drawing the metal at the top of the thread, thereby increasing the depth of the threads. If for any reason it is necessary to produce a thread of full depth, "serial" taps should be used with a good grade of lubricant. Serial taps differ from ordinary taps which are made in sets in the following particular: Only the bottoming tap equals the full diameter of the thread, the other taps being progressively smaller, so as to distribute the work more evenly between the three taps.

When using U. S. standard threads, an ordinary cold-punched nut, if reamed out until it has but 50 per cent depth of thread, will not strip; neither will it strip the tops off the bolt thread — *the bolt always breaks*. If, in tapping, we produce nut threads which are stronger than the bolt, with a reasonable margin of safety, nothing is gained by attempting to make fuller or deeper nut threads. Such attempts only make unnecessary waste in tapping operations Tests made by the Wells Brothers Co. have demonstrated that a full depth of thread in a nut is *practically* no stronger than 75 per cent depth of thread, and that 75 per cent depth of thread is only 20 per cent stronger than 50 per cent depth of thread. (Theoretically it might seem to be

Table I. Tap Drill Sizes for U. S. Standard Threads

These tap drill diameters allow approximately 75 per cent of a full thread

Thread Diam.	No. of Threads	Diam. Tap Drill	Thread Diam.	No. of Threads	Diam. Tap Drill	Thread Diam.	No. of Threads	Diam. Tap Drill
1/4	20	13/64	13/16	10	45/64	1 3/8	6	1 7/32
5/16	18	1/4	7/8	9	49/64	1 1/2	6	1 11/32
3/8	16	5/16	15/16	9	53/64	1 5/8	5 1/2	1 7/16
7/16	14	23/64	1	8	7/8	1 3/4	5	1 35/64
1/2	13	27/64	1 1/16	8	15/16	1 7/8	5	1 43/64
9/16	12	15/32	1 1/8	7	63/64	2	4 1/2	1 25/32
5/8	11	17/32	1 3/16	7	1 3/64	2 1/4	4 1/2	2 1/32
11/16	11	19/32	1 1/4	7	1 7/64	2 1/2	4	2 1/4
3/4	10	41/64	1 5/16	7	1 11/64	2 3/4	4	2 1/2

Table II. Tap Drill Sizes for V-threads

These tap drill diameters allow approximately 75 per cent of a full thread

Thread Diam.	No. of Threads	Diam. Tap Drill	Thread Diam.	No. of Threads	Diam. Tap Drill	Thread Diam.	No. of Threads	Diam. Tap Drill
1/4	20	3/16	13/16	10	43/64	1 3/8	6	1 5/32
5/16	18	15/64	7/8	9	23/32	1 1/2	6	1 9/32
3/8	16	19/64	15/16	9	25/32	1 5/8	5	1 23/64
7/16	14	11/32	1	8	53/64	1 3/4	5	1 31/64
1/2	12	25/64	1 1/16	8	57/64	1 7/8	4 1/2	1 37/64
9/16	12	29/64	1 1/8	7	15/16	2	4 1/2	1 45/64
5/8	11	1/2	1 3/16	7	1	2 1/4	4 1/2	1 31/32
11/16	11	9/16	1 1/4	7	1 1/16	2 1/2	4	2 11/64
3/4	10	39/64	1 5/16	7	1 1/8	2 3/4	4	2 27/64

Table III. Tap Drills for Pipe Taps

Size of Tap	Drills for Briggs Pipe Taps	Drills for Whitworth Pipe Taps	Size of Tap	Drills for Briggs Pipe Taps	Drills for Whitworth Pipe Taps	Size of Tap	Drills for Briggs Pipe Taps	Drills for Whitworth Pipe Taps
1/8	21/64	5/16	1 1/4	1 15/32	1 15/32	3 1/4	....	3 1/2
1/4	29/64	27/64	1 1/2	1 23/32	1 25/32	3 1/2	3 13/16	3 3/4
3/8	19/32	9/16	1 3/4	......	1 15/16	3 3/4	....	4
1/2	23/32	11/16	2	2 3/16	2 5/32	4	4 3/16	4 1/4
5/8	....	25/32	2 1/4	......	2 13/32	4 1/2	4 11/16	4 3/4
3/4	15/16	29/32	2 1/2	2 11/16	2 25/32	5	5 1/4	5 1/4
7/8	....	1 1/16	2 3/4	....	3 1/32	5 1/2	....	5 3/4
1	1 3/16	1 1/8	3	3 5/16	3 9/32	6	6 5/16	6 1/4

50 per cent stronger.) From 75 per cent depth of thread, the power required to tap rapidly increases as a full depth of thread is approached.

The breaking strain of the average ½-inch, U. S. standard commercial tap as found on the market is approximately 700 inch-pounds. Tapping common cold-punched nuts with *new* taps, the *average* torque required is as follows, using mineralized lard oil as a lubricant:

75 per cent depth of thread......	199 inch-pounds
90 per cent depth of thread......	365 inch-pounds
100 per cent depth of thread......	575 inch-pounds

Therefore, in attempting to tap out a full depth thread, the strain is too close to the breaking strain of the tap to be advisable. As the tap wears and becomes dulled, the torque required may equal the breaking strain of the tap, but in tapping 75 per cent depth of thread there is a factor of safety of practically 3. On a ½-inch tap the difference in cut between 75 per cent and 90 per cent depth of thread is only 0.0075 inch; yet, under the favorable conditions given, the power required to make the deeper thread is nearly double. When tapping dry, or using machine oil, the ratio of increase in power is very much greater than that given.

Table IV. Tap Drill Sizes for S. A. E. Standard Threads

Diam. of Tap	No. of Threads	Diam. of Tap Drill	Diam. of Tap	No. of Threads	Diam. of Tap Drill	Diam. of Tap	No. of Threads	Diam. of Tap Drill
¼	28	0.213	9/16	18	0.500	1	14	0.921
5/16	24	0.272	⅝	18	0.562	1⅛	12	1.031
⅜	24	0.332	11/16	16	0.625	1¼	12	1.156
7/16	20	0.386	¾	16	0.687	1⅜	12	1.281
½	20	0.437	⅞	14	0.796	1½	12	1.406

Inasmuch as with 75 per cent depth of thread the nut is stronger than the bolt — so much stronger as to break the bolt without even "starting" the nut threads — and, inasmuch as 75 per cent depth of thread possesses practically all the strength of a full depth thread, one can readily see that the 75 per cent depth is more preferable to the full depth. For instance, grit or dirt,

Table V. Tap Drill Sizes for A. S. M. E. Standard Machine Screws

These tap drill diameters allow approximately 75 per cent of a full thread

No. of Screw	Diam. of Thread	Threads per Inch	Tap Drill Diam.	Drill No. or Letter	No. of Screw	Diam. of Thread	Threads per Inch	Tap Drill Diam.	Drill No. or Letter
Standard Machine Screws									
0	0.060	80	0.0465	56	12	0.216	28	0.180	15
1	0.073	72	0.0595	53	14	0.242	24	0.201	7
2	0.086	64	0.070	50	16	0.268	22	0.221	2
3	0.099	56	0.081	46	18	0.294	20	0.242	*C*
4	0.112	48	0.089	43	20	0.320	20	0.266	*H*
5	0.125	44	0.1015	38	22	0.346	18	0.290	*L*
6	0.138	40	0.113	33	24	0.372	16	0.302	*N*
7	0.151	36	0.120	31	26	0.398	16	0.332	*Q*
8	0.164	36	0.136	29	28	0.424	14	0.348	*S*
9	0.177	32	0.147	26	30	0.450	14	0.377	*V*
10	0.190	30	0.157	22	....	.....	....	......	....
Special Machine Screws									
1	0.073	64	0.055	54	9	0.177	24	0.136	29
2	0.086	56	0.067	51	10	0.190	32	0.159	21
3	0.099	48	0.0785	47	10	0.190	24	0.147	26
4	0.112	40	0.086	44	12	0.216	24	0.173	17
4	0.112	36	0.082	45	14	0.242	20	0.191	11
5	0.125	40	0.0995	39	16	0.268	20	0.213	3
5	0.125	36	0.098	40	18	0.294	18	0.238	*B*
6	0.138	36	0.111	34	20	0.320	18	0.266	*H*
6	0.138	32	0.1065	36	22	0.346	16	0.281	*K*
7	0.151	32	0.120	31	24	0.372	18	0.316	*O*
7	0.151	30	0.116	32	26	0.398	14	0.323	*P*
8	0.164	32	0.1285	30	28	0.424	16	0.358	*T*
8	0.164	30	0.1285	30	30	0.450	16	0.386	*W*
9	0.177	30	0.144	27	....	.....	....	......	....

in the case of 75 per cent depth, works down to the root of the bolt threads and gives no trouble. In a full depth thread it is forced into the walls, creating unnecessary friction and destroying the smoothness of the threads. Therefore tap drills which will give 75 per cent depth of thread in the nut or tapped hole are recommended. However, as commercial drills do not exactly meet these figures, by using the next larger commercial size, good results are obtained. The use of these sizes of drills is proving a revelation in tapping economy to many shops. A very large percentage of commercial taps break before they have been used long enough to require sharpening. This tremendous breakage is seldom the fault of the taps. Strains are often brought to bear upon taps which no metal can possibly withstand. The most important cause is the use of too small holes. It is not by any means uncommon to find taps used in holes which are smaller than the root diameter of the tap.

The sizes of tap drills to use for various standard threads are given in the accompanying Tables I to V, inclusive. The diameters of tap drills can also be found by the formula $D = T - 0.75 \times 2d$, in which D = drill diameter, T = diameter of tap or thread, and d = depth of thread. The diameters obtained by this formula allow for a thread having 75 per cent of the standard depth which is sufficient for general work. The formula applies to either U. S. standard or V-threads.

The practice of a prominent manufacturer is to make a distinction in the sizes of tap drills according to whether the hole is to be hand or machine tapped; and Table VII gives the amount to subtract from the outside diameter of the screw to find the diameter of the tap drill for both machine and hand tapping for different numbers of threads per inch of U. S. standard form. In this case the tap drills for machine tapping will give 0.8 of a full thread and those for hand tapping 0.9 of a full thread.

Table VI. Tap Drills for Small V-thread Taps

Size of Tap	No. of Threads	Drill No.	Size of Tap	No. of Threads	Drill No.	Size of Tap	No. of Threads	Drill No.
1/16	60	55	9/64	32	32	13/64	28	20
5/64	60	52	9/64	36	35	13/64	32	20
3/32	48	47	9/64	40	33	7/32	22	19
3/32	56	46	5/32	30	31	7/32	24	18
3/32	60	46	5/32	32	30	7/32	28	17
7/64	32	45	5/32	36	29	7/32	30	15
7/64	36	44	5/32	40	29	7/32	32	13
7/64	40	43	11/64	32	30	15/64	22	10
7/64	44	43	11/64	36	29	15/64	24	10
7/64	48	42	11/64	40	28	15/64	28	9
1/8	32	40	3/16	24	27	15/64	32	9
1/8	36	38	3/16	28	26	1/4	20	7
1/8	40	37	3/16	30	23	1/4	22	5
1/8	44	36	3/16	32	23	1/4	24	2
9/64	30	35	13/64	24	21	1/4	32	2

Power Required for Tapping. — The size of the hole affects very materially the power required for tapping. This is particularly important in machine tapping. The power is also affected by the kind of lubricant used, by the condition of the tap as regards being sharp or dull, by the shape of the cutting edges and their effect on the shape of the chip, and by the shape of the flutes. The shape of the tap at the end is another important factor.

As almost all machine tapping is in through holes, and bottoming taps are seldom used, experiments have been made to determine the effects of sharpening or grinding the taps back from the end for a varying number of threads, so as to ascertain the effect of dividing the work between a greater or smaller number of cutting teeth. By repeated tests and careful records it has been found that it requires approximately 25 per cent more power to drive a tap which has been ground back only four threads (which in a four-fluted tap divides the work between 16 teeth) than for one which has been ground back six threads (thus having 24 cutting teeth); the latter tap produces a much smoother thread and cuts more closely to size.

Table VII. Table for Finding Tap Drills when nearly a Full Thread is Required

Threads per Inch	Amount to Subtract from Outside Diameter to find Diameter of Tap Drill		Threads per Inch	Amount to Subtract from Outside Diameter to find Diameter of Tap Drill		Threads per Inch	Amount to Subtract from Outside Diameter to find Diameter of Tap Drill	
	Machine Tapping	Hand Tapping		Machine Tapping	Hand Tapping		Machine Tapping	Hand Tapping
64	0.0162	0.0183	26	0.0400	0.0450	9	0.1155	0.1299
60	0.0173	0.0195	24	0.0433	0.0487	8	0.1299	0.1461
56	0.0186	0.0209	22	0.0472	0.0531	7	0.1485	0.1670
50	0.0208	0.0234	20	0.0520	0.0584	6	0.1732	0.1949
48	0.0216	0.0243	18	0.0577	0.0649	5½	0.1889	0.2126
44	0.0236	0.0266	16	0.0649	0.0731	5	0.2078	0.2338
40	0.0260	0.0292	14	0.0742	0.0835	4½	0.2309	0.2598
36	0.0289	0.0325	13	0.0799	0.0899	4	0.2598	0.2923
32	0.0325	0.0365	12	0.0866	0.0974	3½	0.2969	0.3340
30	0.0346	0.0390	11½	0.0904	0.1017	3	0.3464	0.3897
28	0.0371	0.0417	11	0.0945	0.1063	....	......	......
27	0.0385	0.0433	10	0.1039	0.1169	....	......	......

Table VIII contains figures which are the average of a large number of tests. The maximum and minimum torque in inch-pounds is given. The taps were ½-inch U. S. standard; depth of tapped hole, ½ inch; and diameter of tap drill, 0.420 inch. Table X, "Effect of Lubricants and Tap Drill Diameters when Tapping," shows the variation in torque, the number of breakages and the quality of thread resulting from the use of different lubricants and three different sizes of tap drills. These data represent a long series of tests. For comparative purposes, the breaking strength is taken as 100, and the torque required for tapping is given as a percentage of this number. The test pieces were common hexagon, cold-punched nuts accurately reamed to the sizes specified, and regular ½-inch U. S. standard taps were used. The torque required to break a properly made ½-inch U. S. standard tap is approximately 1000 inch-pounds; hence, by multiplying the percentage given in the table by 10, the average actual torque in inch-pounds can be obtained. This data was obtained from a paper by F. O. Wells, read before the American Society of Mechanical Engineers.

Table VIII. Average Torque in Inch-pounds for Tapping Different Materials

(One-half inch U. S. tap; diameter of tap drill, 0.420 inch.)

Material Tapped	Torque in Inch-pounds	
	Maximum	Minimum
Hexagon drawn brass	64	63
Crucible tool steel	261	258
Cold-punched hexagon steel nuts	182	176
Hexagon screw stock	205	189
Drawn hexagon phosphor-bronze	234	221

The power required for driving pipe taps is given in Table IX, which includes nominal pipe tap sizes from 2 to 8 inches. The holes to be tapped were reamed with standard pipe tap reamers before tapping. The horsepower recorded was read off just before the tap was reversed. The table gives the net horsepower, deductions being made for the power required to run the machine without a load. The material tapped was cast iron, except in two instances, where steel casting was tapped. It will be seen that nearly double the power is required for tapping steel casting. The power varies, of course, with the conditions. More power than that indicated in the table will be required if the cast iron is of a harder quality or if the taps are not properly relieved. The taps used in these experiments were of the inserted-blade type, the blades being made of high-speed steel.

Lubricants for Tapping. — The breakage of taps can be reduced greatly by using the proper lubricant. A good grade of animal lard oil, sperm oil, and graphite and tallow mixtures (10 per cent graphite, 90 per cent tallow) are the best lubricants to use when tapping steel or iron. A good soap compound is better than "mineral lard oil." Machine oil is a poor tapping lubricant. By referring to the column "Power Required," in Table X, it will be seen that the power required when using sperm oil is 16.5, as compared with 34.2 when machine oil is used. Incidentally, this increase is almost as great as that due to decreasing the diameter of the tap drill from 0.425 to 0.400 inch when using sperm oil, the increase being from 16.5 to 35.5. This shows that a poor lubricant may increase the power for tapping as much as would a considerable reduction in the diameter of the hole to be tapped. For cast iron, soap compounds give excellent results, and lard oil is also used. Oil for cast iron, however, has the disadvantage of causing the chips to stick in the tap flutes,

Table IX. Power Required for Tapping

Nominal Size of Pipe Tap, Inches	Revolutions per Minute	Net Horsepower	Thickness of Metal, Inches
2	40	4.24	1⅛
2½	40	5.15	1⅛
*2½	38.5	9.14	1⅛
3	40	5.75	1⅛
*3	38.5	9.70	1⅛
3½	25.6	7.20	1¾
4	18	6.60	2
5	18	7.70	2
6	17.8	8.80	2
8	14	7.96	2½

* Tapping steel casting; other tests in cast iron.

thus preventing the lubricant from reaching the cutting edges; hence a thinner lubricant is preferable. When tapping long holes in cast iron, a very small amount of kerosene will facilitate the work.

Speeds for Tapping. — To secure good results in machine tapping it is necessary to run the tap at the proper speed. Of course, speed depends a great deal on the metal being tapped and the condition and quality of the tap. Under ordinary conditions, with the tap in good shape, speeds of 15 to 20 feet per minute have been found satisfactory. The accompanying Tables XI and XII give speeds for taps of various standard diameters and are merely intended to serve as a general guide.

Table X. Effect of Lubricants and Tap Drill Diameters when Tapping

Lubricant	Diameter Tap Hole, 0.425 Inch (75 per cent Thread)			Diameter Tap Hole, 0.410 Inch (90 per cent Thread)			Diameter Tap Hole, 0.400 Inch (Full Thread)		
	Power Required *	Per cent of Breakages	Quality of Thread	Power Required *	Per cent of Breakages	Quality of Thread	Power Required *	Per cent of Breakages	Quality of Thread
Animal Lard Oil	15.9	0	Smooth	...	...	......	...	...	....
Sperm Oil	16.5	0	Smooth	23	0	Smooth	35.5	0	Smooth, Taps Torn
Graphite, 10 per cent; Tallow, 90 per cent	16.9	0	Smooth	...	...	......	...	...	....
Cataract Soap Compound	18.9	0	Smooth	25.1	0	Smooth	41	0	Slightly Rough, Taps Torn
Mineral Lard Oil	19.9	0	Smooth	36.5	0	Smooth	57.5	0	Smooth, Taps Torn
Tapped Without Oil	29.9	14	Rough	60.2	50	Rough	71.8	66	Torn, Partly Stripped
Machine Oil	34.2	15	Torn	62.5	71.5	Badly Torn	100	100	Torn, Chips Wedged

* In per cent of breaking strength of tap.

Table XI. Speeds for Standard Taps in Revolutions per Minute

Diameter of Tap	Cast Iron	Wrought Iron	Diameter of Tap	Cast Iron	Wrought Iron
3/16	340	265	1	72	57
1/4	295	230	1 1/8	63	50
5/16	240	190	1 1/4	57	45
3/8	197	152	1 3/8	51	41
7/16	170	122	1 1/2	46	38
1/2	145	114	2	34	28
5/8	117	91	2 1/4	30	26
3/4	96	76	2 1/2	26	23
7/8	84	65	....	....	....

Table XII. Speeds for Tapping Nuts

Peripheral Speed, 10 Feet per Minute				Peripheral Speed, 15 Feet per Minute				Peripheral Speed, 20 Feet per Minute			
Tap Diam.	Rev. per Min.	Tap Diam.	Rev. per Min.	Tap Diam.	Rev. per Min.	Tap Diam.	Rev. per Min.	Tap Diam.	Rev. per Min.	Tap Diam.	Rev. per Min.
1/8	Faster than 10 ft. per minute	1 1/2	25	1/8	460	1 1/2	38	1/8	612	1 1/2	Slower than 20 ft. per minute
1/4		1 5/8	23	1/4	230	1 5/8	35	1/4	306	1 5/8	
5/16		1 3/4	22	5/16	188	1 3/4	32	5/16	244	1 3/4	
3/8		1 7/8	20	3/8	153	1 7/8	30	3/8	204	1 7/8	
7/16		2	19	7/16	131	2	28	7/16	176	2	
1/2		2 1/4	17	1/2	115	2 1/4	25	1/2	153	2 1/4	
9/16		2 1/2	15	9/16	102	2 1/2	22	9/16	136	2 1/2	
5/8		2 3/4	14	5/8	93	2 3/4	20	5/8	122	2 3/4	
3/4		3	12	3/4	75	3	18	3/4	102	3	
7/8		3 1/4	11	7/8	65	......	....	7/8	88	3 1/4	
1	38	3 1/2	10	1	55	......	....	1	76	3 1/2	
1 1/8	34	3 3/4	9	1 1/8	50	......	....	1 1/8	....	3 3/4	
1 1/4	30	4	8	1 1/4	45	......	....	1 1/4	....	4	
1 3/8	28	......	....	1 3/8	40	......	....	1 3/8	....	......	

Removing a Broken Tap. — When a tap is broken near the surface, it can easily be removed by driving on both sides (as indicated by the arrows in Fig. 13), using drifts or blunt cape chisels. Two men should start at the same time, with light blows, and when they are striking in unison the force of the blows should be increased, as may be required. By driving on both sides, the tap is not wedged against one side of the hole, as when using a single drift, but is forced to rotate. This is an old, but very effective method. Another method of removing broken taps,

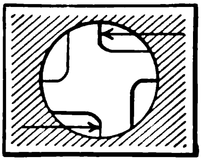


Fig. 13

which has proved very effective in some cases, is to inject into the hole a little nitric acid, diluted in the proportion of about one part acid to five parts water. The action of the acid upon the steel loosens the tap so that it usually can be removed readily. The remaining acid should afterwards be washed out of the hole so that it will not continue to eat the threads.

CHAPTER IV

GRINDING TWIST DRILLS

The point or cutting end of a drill should be carefully ground because a poorly formed drill affects the quality and quantity of the work produced. It is difficult to grind drills theoretically correct by hand, at least in a reasonable length of time, and special grinders are often used for this purpose. Many shops, however, do not have such grinders, but if the requirements of a correctly formed drill point are known, it is possible, with practice, to grind a drill satisfactorily by hand. The requirements, briefly stated, are as follows: The two cutting edges should incline at the proper angle *a* with the axis, as shown at *A* in Fig. 1; each edge should have the same inclination and be of the same length; the angle of clearance *c* (see Fig. 1, at *B*) should be sufficient to permit the drill to cut freely; the clearance should be the same on both sides and increase toward the point of the drill.

Effects of Incorrect Grinding. — At *A* in Fig. 2 is shown the relation between a drill point and a hole when the cutting edges are not at the same angle with the axis. When both cutting edges are ground to the same angle, one edge counteracts the tendency of the other to spring away from the cut (provided the clearance is also correct), but when these angles are different, as shown, one edge will do more work than the other, thus subjecting the drill to an unbalanced twisting or torsional strain. The drill will also be forced sidewise, which will result in an enlargement of the hole.

The effect produced when the lengths of the cutting edges are unequal is illustrated at *B*. As the drill revolves about the center or point *p*, when it is fed into the metal, the horizontal distance *x* from this point to the side furthest away will equal the radius of the hole, which will, of course, be larger than the drill diameter if the point is not central; therefore, each cutting edge should have the same length, as otherwise the drill will cut a hole larger than its diameter. At *C* a drill point is shown having cutting edges inclined at different angles to the axis and of different lengths, thus combining the disadvantages mentioned in the foregoing.

Correct Grinding Method. — Each cutting edge should be ground to an angle of 59 degrees with the axis. When grinding, support the drill on the tool-rest of the grinder, and move it slowly back and forth, in order that any unevenness in the wheel-face will not affect the straightness of the cutting edge. Use preferably the face of the grinding wheel in order to derive benefit from the cooling water, and grind slowly so that the temper of the drill will not be affected. The position of the drill in relation to the face of the wheel should be such that the angle *a* (Fig. 1), which the cutting edges make with the axis, and the angle of clearance *c* will be ground as nearly correct as can be judged. The angle *a* can be tested by using a protractor as indicated at *C*. The length of each edge should also be measured with a scale and corrected by grinding, if unequal, care being taken not to change the angle of the cutting edge, if this is found correct.

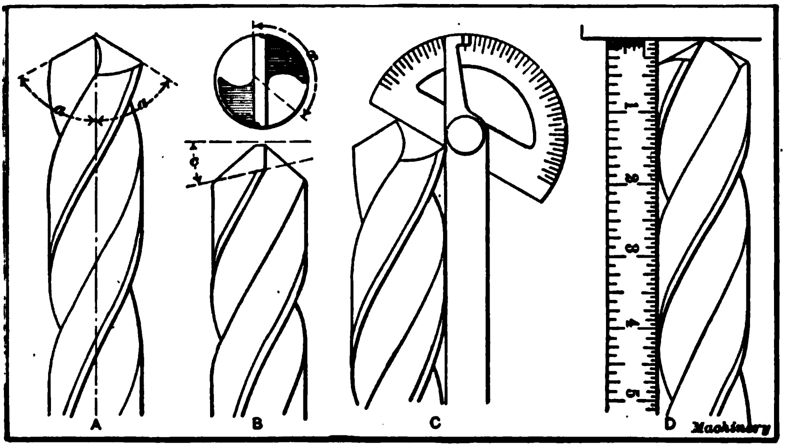


Fig. 1. Views showing Angles to be Considered when Grinding Drills, and Methods of Measuring Lip Angle and Clearance

It should be mentioned that there is a difference of opinion as to the best angle *a* for the cutting edges. As this angle is decreased, the pressure required for feeding a drill downward through the metal becomes less, but the length of each cutting edge is increased, with the result that more power is required to turn the drill. An included angle of 118 degrees (59 degrees between the cutting edge and axis) is thought by some to equalize the thrust and torsion to the best advantage, while others advocate much more acute angles. An included angle at the point of 118 degrees and a clearance angle of 12 degrees insures, however, satisfactory results under ordinary conditions, when the grinding is done by hand or in machines that give a greater clearance angle at the outer edge than at the center. If correct grinding can be assured, the angle of clearance increasing towards the center of the drill, the clearance angle can ordinarily be reduced.

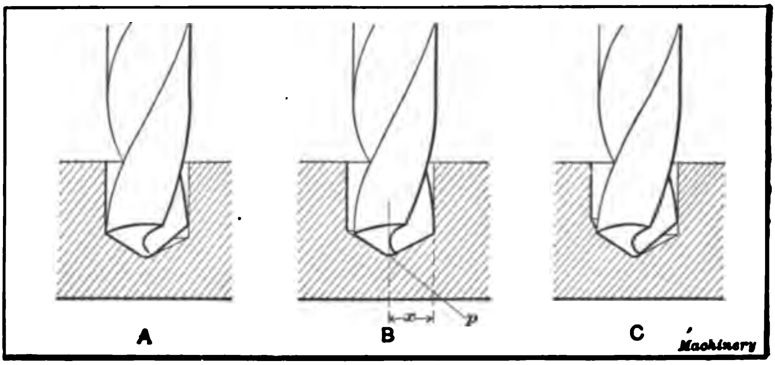


Fig. 2. Three Examples of Incorrect Drill Grinding

After each side or edge has been ground, the end of the drill will appear somewhat as shown in the upper view at *B*, Fig. 1, the unshaded portion representing the ground surface. That part indicated by the shaded lines should then be ground away so that it will not interfere with the downward movement of the cutting edge when the drill is in use. When grinding this part, support the inner end of the drill on the tool-rest, and move the outer end so as to produce a surface which is approximately conical in form. The grinding should be continued until the conical surface is blended into the flat (unshaded) part, previously ground.

Clearance. — The clearance for each cutting edge may be tested by placing the drill point against a flat surface and then slowly revolving it close to a scale held in the position shown at *D*. If the clearances are not alike, this will be indicated by their relative positions to the graduation marks on the scale, as the drill is turned. The clearance is a very important feature in drill grinding, and the splitting of drills through the web is usually an indication either of incorrect clearance or excessive feed. If the end of a drill conforms exactly to the conical shape of the bottom of a hole, evidently it will not cut, because the lack of clearance would make it impossible to sink the cutting edges into the metal; therefore, when there is insufficient clearance for a given feed, the drill binds back of the cutting edges and is subjected to an excessive twisting strain. Theoretically, the clearance should be just enough to permit the drill to cut freely, because excessive clearance weakens the cutting edges. The Cleveland Twist Drill Co. advocates a clearance angle c of 12 degrees at the periphery of the drill, with a gradual increase toward the center, until the line joining the two cutting edges makes an angle x somewhere between 125 and 135 degrees, as shown in the plan view at *B*. When soft metal is to be drilled and heavier feeds are possible the angle of clearance may be increased to 15 degrees, whereas for hard material such as tool steel, for example, the amount of clearance is diminished, as a fine feed must necessarily be used and a strong cutting edge is required.

As previously stated, clearance should gradually increase toward the drill point. The reason for this will be apparent by considering the movement of two points *A* and *B* (Fig. 3) on the cutting edge, as the drill is fed downward, one point being much nearer the center than the other. Assuming that the feed is constant, the path described by each of these points will correspond to that indicated by the helical lines shown. As the vertical distance x that each point moves per revolution of the drill will be the same, the angle of the smaller helix or spiral will be greater than that of the larger one. The angle in each case indicates the minimum clearance necessary at that particular point for a feed per revolution equivalent to the distance x. The amount of feed indicated has been greatly exaggerated in order to make the comparison clear.

Drill-grinding Machines. — As the correct grinding of drills by hand requires considerable time, even by an experienced workman, special grinders are often employed for this purpose. A type which has been used extensively is illustrated in Fig. 4. This grinder so controls the movement of the drill with relation to the grinding wheel that the end is given the correct form. The drill to be ground is first placed between the caliper jaws *C* which are adjusted to the diameter of the drill. This adjustment is effected by loosening lever *L* and shifting the sliding jaw the required amount. The drill is then placed in V-shaped holders *H* and it is turned to bring the lower lip against a hardened stop at the grinding end. In this way the drill is properly centered and located with reference to the face of the wheel. The point of the drill should project about $\frac{1}{16}$ inch beyond the lip-rest, and the shank end is placed against an adjustable foot-stop *F*. The entire drill-holding device should be clamped in such a position that the drill will nearly touch the grinding wheel when the holder is swung at right angles to the wheel-face. The grinding is done by oscillating the drill-holder in bearing *B*, which is inclined to the face of the grinding wheel, as shown. After one lip is ground, the drill is turned over for grinding the opposite side. As the grinding proceeds, the drill is gradually fed against the wheel by turning micrometer screw *M*, which pushes the foot-stop *F* forward. This screw should be turned to the same graduation for grinding each side of the drill, in order to secure cutting edges of equal length. When reversing or removing the drill, the holder should be swung to the extreme left.

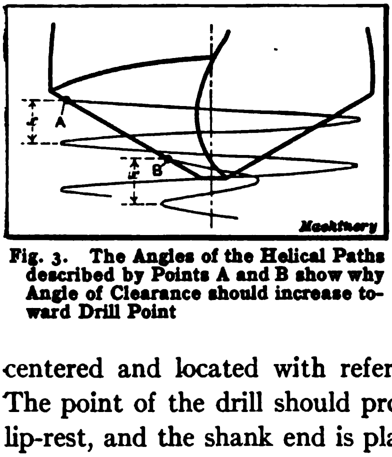


Fig. 3. The Angles of the Helical Paths described by Points A and B show why Angle of Clearance should increase toward Drill Point

The adjustment of the caliper jaws *C*, previously referred to, is done to give drills of different diameter a standard clearance. As these jaws are opened to fit a drill of given size, the lip-rest and end of the drill are advanced with relation to the axis of bearing *B*, about which the holder rotates. If the opening between the jaws is made greater than the diameter of the drill, the clearance will be less than the standard, and, inversely, a smaller opening will increase the clearance. The proper way, however, to vary the angle of clearance is by loosening handwheel *A* and turning an eccentric bushing in which the holder rotates, thus

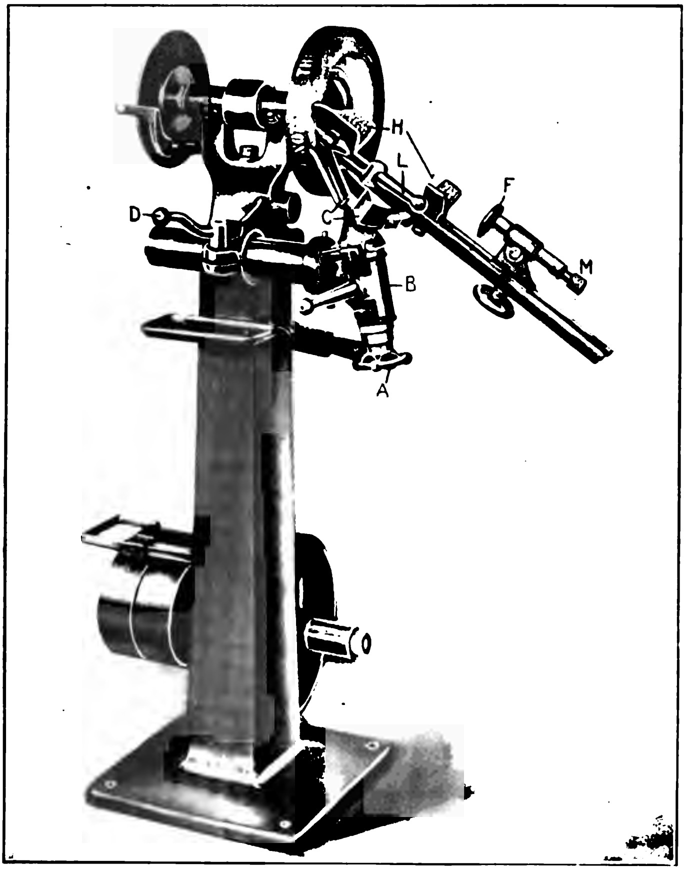


Fig. 4. Grinder for Sharpening Drills

moving the axis of rotation toward or away from the grinding wheel. This adjustment is indicated by suitable graduations, and it is not changed unless it is desired to vary the standard clearance. The entire holder can be adjusted in or out by loosening clamping lever *D*, in case this is necessary to compensate for the wear of the wheel-face or to set the holder in correct relation to a new wheel.

When a drill has been shortened considerably by repeated grinding, the point or web becomes thicker, because the grooves of twist drills gradually decrease in depth toward the shank. (The grooves are milled in this way in order to strengthen the drill.) As the width of the point increases, more pressure is required for feeding the drill, and, to overcome this, the point should be made thinner by grinding. The grinder shown in Fig. 4 has a thin elastic emery wheel on the left end of the spindle, which is provided for the thinning of drill points. Care should be taken to grind away an equal amount of stock on each side of the point in order to keep it central.

CHAPTER V

DRILLING DEPARTMENT EQUIPMENT AND REQUIREMENTS

Rapid drilling in a shop is very necessary. It is, of course, important from the standpoint of economy in drilling alone, but the main feature to be considered is the fact that when work is sent to the drills, it is generally in steady progress of manufacture, and, under ordinary conditions, some of the assemblers will be found waiting for the drilling operations to be finished. The object of this chapter is to analyze the elements that enter into the problem of rapid drilling and point out some of the usual defects in methods and processes.

Selection of Drilling Machines. — The starting point for minimizing drilling costs naturally will begin with a discussion of the machine tool. There are several types of drilling machines, each adapted to a certain class of work. Sensitive drill presses having from one to four spindles are convenient for light work. The spindles have vertical movements by means of hand levers and are balanced by coiled springs. The table is counterbalanced by a weight and may be swung around as well as raised and lowered. These machines drill holes up to ½ inch in diameter. Besides having the advantage of high speed, the drive, which is some form of friction drive, lessens the danger of breaking drills.

The box column, high-duty type of drill press, having a table of the knee type, is the best form for comparatively small work that requires extreme accuracy and is drilled without the use of drill jigs. On account of the great rigidity of this type of drill, it is particularly well adapted for the making of jigs and fixtures. For this work, however, better results will be obtained by substituting a compound table, so that the work remains clamped to the table until all the drilling or boring operations are completed.

Gang drills, which consist of several stationary overhanging arms bolted to a common base and having a common work-table, are economical where several operations have to be performed on one hole. One operator usually runs the gang.

Radial drills are most convenient for handling heavy work, where a number of holes have to be drilled at different points. This type of drilling machine has a wider range of usefulness than any other, but, from the very nature of its design, it is imperative that the column and arm be made unusually stiff. The amount of work that can be turned out from a modern, high-duty radial drill, when driven by a variable speed motor of ample power and using the new flat-twisted drills, is astounding. A well-built, modern radial drill meets all general requirements for accurate drilling, tapping, and reaming, but when extreme accuracy is required, and when the machine is used for boring, jigs are needed to guide the tools. Universal radial drills are very handy for large work having holes to be drilled on an angle; but for angular work that can be drilled by clamping it to the swivel shelf of a box table, or where angular work is only occasionally met with, the plain radial drill is to be preferred.

Radial drills are sometimes placed in gangs and driven from a single shaft, a very good arrangement for long, heavy work. A very efficient and inexpensive horizontal drill for drilling, tapping, reaming, and boring consists of a radial drill head mounted on a vertical column. This column should travel in suitable guides on a base having a surface for supporting the work.

Adjustable multiple-spindle drills are designed for drilling, simultaneously, a number of holes in groups of square, circular, or other geometrical forms. The spindle heads are provided with vertical adjustment on the arms, to compensate for variation in length of drills or to enable drilling to be done at different levels, the amount of this adjustment varying according to the diameter of the spindles. In setting the spindles, the work jig is bolted to the table, the drills are inserted in the jig holes, and the arms are adjusted to bring the spindles into proper alignment and are then clamped. These machines are often used without the aid of drill jigs by clamping the work against suitable stops on the table. There are three standard types of multiple-spindle drilling machines:

1. The smaller sizes have the head fixed on the column and are provided with the knee type of table. The table is counterbalanced and its movements are controlled by adjustable hand and foot levers. This type is furnished with a No. 1 or No. 2 Morse taper hole in the spindles.

2. A heavier type consists of a work base having a column bolted to it. The head slides on this column and has a quick traverse by hand and power. A box table is furnished to hold small work. This type generally takes a No. 3 Morse shank.

3. The largest size of multiple-spindle drills have a head sliding between two columns. The work-table is mounted on wheels and is arranged to run on a track for bringing the work under the drills. This type is usually motor-driven and has No. 4 Morse taper holes.

Any of these types may be furnished with a square, rectangular, or circular head. The spindles are all driven through universal couplings from a central gear. Power feed, automatic and positive stops are features common to all.

The value of multiple-spindle drills for duplicate work manufactured in large quantities can hardly be overestimated; but for work made in lots of twelve pieces or less, it is often quite a problem to decide just what class of work this machine will handle more economically than the radial drill. This is because the time required to set the spindles of a multiple drill to a complicated lay-out is an appreciable percentage of the total time required to complete the job. The lay-out often involves two or more settings of the work or the spindles, and this nullifying condition also enters into the problem. Provision should be made for tapping on these machines, as several holes can be tapped simultaneously.

General Requirements of Drilling Machines. — Accurate tests have demonstrated that the average drilling machine should have fully double the driving power contemplated in its design.

This is a point that must be considered carefully, and especially in the case of multiple-spindle drills. A proper increase in driving power means heavier motors, wider pulleys, stronger gearing, and larger bearings. Immediately there follows the question of rigidity. The fact that ample driving power and rigidity are the vital features in a drilling machine cannot be repeated too often. The fullest possibilities of economy attending the use of the new high-speed steel, flat-twisted drills cannot be realized unless these provisions are made. An idea of the amount of power required to drive these drills to their limit of endurance may be obtained from the data presented in Table I, which was obtained through tests made at the Pond Works of the Niles-Bement-Pond Co. It was desired to obtain power data for a $1\frac{3}{8}$-inch drill, but as several makes of $1\frac{1}{3}\frac{1}{2}$-inch drills were available, these were used for the test, the object being to determine the amount of driving power required by selecting for the data the drill that would stand the maximum amount of speed and feed.

Table I. Power Data on High-Speed Steel Flat-twisted Drills Tested on Pond Radial Drill

Size of Drill, Inches	Peripheral Speed, Feet per Minute	Revolutions per Minute	Feed per Revolution	Number of Holes Drilled	Condition of Drill	Horsepower Consumed	Material Drilled
$1\frac{11}{32}$	150	426	0.016	9	Good	11.9	Cast-iron plate, 2¾ inches thick
$1\frac{11}{32}$	185	528	0.016	30	Needed grinding	12.8	
$1\frac{11}{32}$	210	597	0.016	4	Burned off at point	17.9	
$1\frac{11}{32}$	85	241	0.016	2	Burned off at point	11.9	Machine steel, 4 inches thick
$1\frac{11}{32}$	85	241	0.009	14	Needed grinding	7	

The very simplest form of driving mechanism is to be preferred. Undoubtedly the best type of drive is by a direct-connected 6 to 1 speed-range motor, through gears and splined shafts. Many experienced mechanics do not favor speed-boxes for the reason that they seldom stand for any length of time the severe usage imposed upon them in modern drilling departments.

The feed range of a modern drilling machine meets all general requirements.

A motor should never be mounted on top of the drill column, according to the opinion of many engineers. While this is the practice with some makers, the plan is open to the practical objection that the vibration caused by unbalanced mechanical and electrical elements in the motor becomes a serious matter, especially in machines with a long overhanging arm. This trouble will be largely overcome, however, by bolting the machine to a solid concrete foundation. On account of the high speed at which modern drilling machines are run, it is important that they be provided with self-oiling bearings and ball-thrust bearings for the spindles. A reverse for the spindle in the form of positive clutches is handy for tapping.

Machines that are frequently used for drilling steel should be provided with an oil pump and pan for taking care of the cutting compound. Drill presses that have the knee type of table which is fed by a rack and pinion should be provided with an adjustable counterweight. This is to compensate for varying weights of work that are placed on the table. When this provision is not made, the work-table will fall like a drop-hammer when the feed is released. In the type of multiple-spindle drill with the sliding head, the drive for the rapid power traverse should be through a friction. When drilling deep holes it is, of course, necessary to frequently withdraw the drills from the holes for the purpose of removing chips, and with the positive-driven traverse and automatic stop much time is lost by having to run the head by hand past this stop. Better results would be obtained by using the friction drive and dispensing with the automatic stop. The head could then be run by power to any position, either in starting to drill or running to the bottom of the holes, without danger of breaking the drills or throwing the power traverse belt off. There would also be the added advantage of not having to run the feed by hand.

Some of the smaller sizes of multiple-spindle drills are not furnished with T-slots in the table to clamp the work by, or for use in fastening stops, on the supposition that work will not have a tendency to turn when several drills are operating simultaneously. While the majority of work handled by these machines does not need clamping, it often happens that several operations have to be performed on a single hole, or the axes of two holes in a piece may lie at right angles, or several pieces having one hole in each may be placed side by side and drilled simultaneously, and in each case it would be necessary to use a strap or stops for holding the work.

High-speed Drills. — The high-speed steel, flat-twisted drills have been the most potent factor in reducing drilling costs. It is astonishing to note, however, that the tremendous enthusiasm attending their use is often confined to the first few days; after that the drills are run far below the proper point of speed and feed and the ultimate increase in efficiency, instead of being fully 300 per cent or more over that obtained with the older carbon drills, is nearer 50 per cent. In view of the lack of accurate information relative to the proper amount of speed and feed for the new high-speed steel, flat-twisted drills, Table II will prove interesting. The results shown may not, in all points, prove to be the limit of speed and feed, but are far in excess of those usually secured, so that they can be safely used as a basis upon which to work.

Table II. Speeds and Feeds for High-speed Steel Flat-twisted Drills

Material — Cast Iron			Material — Steel		
Size of Drill	Speed, Rev. per Min.	Feed per Revolution	Size of Drill	Speed, Rev. per Min.	Feed per Revolution
½	1150	0.010	½	535	0.006
⅝	920	0.010	⅝	425	0.006
¾	760	0.012	¾	355	0.006
⅞	655	0.012	⅞	305	0.006
1	570	0.012	1	265	0.006
1⅛	510	0.016	1⅛	235	0.006
1¼	460	0.016	1¼	215	0.006
1⅜	415	0.016	1⅜	195	0.008
1½	380	0.016	1½	180	0.008
1⅝	350	0.020	1⅝	165	0.010
1¾	325	0.020	1¾	150	0.010
1⅞	305	0.020	1⅞	140	0.012
2	285	0.020	2	135	0.012

Many manufacturers of high-speed drills lay great stress on the length of time their drills will run without re-grinding. This, however, is of very little importance, as the question is not how long a drill will run without re-grinding, but how much should a drill be forced so as to produce the most work with a minimum expense for grinding. The crowding of the drilling machine is the important consideration. The question of how long a drill may run without re-grinding sinks into the background when the grinding is done by automatic grinders. It is important to state in this connection that a large supply of drills already ground should be kept in the tool supply room, so that under no circumstances will the drill hands be compelled to wait for their drills. This important point is often overlooked. When drilling steel, the use of cooling agents, such as soft soap, is highly desirable. These should be used very freely.

Miscellaneous Tools. — The new sockets for driving drills and other tools with broken or twisted tangs have saved these tools from the scrap heap. Before these sockets were introduced, many firms avoided the trouble by ordering their tools with taper shanks larger than standard. In principle, this is just what the new sockets do — provide the tools with the next larger size of shank.

Whenever possible, tapping should be done in a machine on account of the time saved. Some form of safety tapping device will prevent the danger of breaking the taps. For tapping several holes simultaneously in a multiple-spindle drill, when the holes are close together, these safety tapping fixtures cannot be used on account of their large diameter. In this case, ordinary tap-holders having a square hole to fit hand taps are used. The tap-holder should be provided with a spring-pin to keep the tap from dropping out. A plug tap is generally used for machine tapping in cast iron. For steel, the hole is drilled larger than standard and two taps are used.

Rose reamers are very extensively used for reaming holes in jig work. These reamers have no cutting edges on the lands, and so permit the reamer to be guided in a cast-iron bushing. Inasmuch as the size is not adjustable, it is essential that the wear of a rose reamer be reduced to the lowest limit, in order to ream a large number of holes of a uniform size. In the standard form of rose reamers, as made by a number of manufacturers, all the flutes are not cut the entire length of the body. It would be a decided improvement to do so, however; when made in the usual form, there is no escape for the chips cut by the edge of the short flutes, especially when reaming to the bottom of a blind hole. The result is that the lands are soon cut and make a rough hole. Experiments and experience prove that a rose reamer having all the flutes cut the entire length and provided with a sufficient number to make the lands about $\frac{1}{4}$ inch wide will outwear the other form three to one.

All boring cutters and counterbore cutters should be made of high-speed steel.

Causes of Lost Time. — The causes of lost time in a drilling department are located so far back toward the fundamentals of production, and the individual units affording the causes are so seemingly unimportant, and such is the difficulty of recognizing these losses, buried as they are in a busy shop, that they are often overlooked or ignored. This is particularly the case in many large shops where the drilling is done in the various assembling departments. It is interesting to note that where this plan is followed, the drills in one department will often be operating at such speeds and feeds as to show a loss of 25 per cent when compared with another department directly beside it, but under another foreman; and, at that, both departments will often be far below the standard of efficiency they should attain.

This condition is due, of course, to the relative efficiency or inefficiency of the foremen. The foremen are not all to blame, however, as they seldom have the time to supervise this work and attend to the other important duties that usually require their attention. When the assembling department is sufficiently large to warrant it, the usual method is to appoint a drill boss who was formerly one of the drill hands, and his experience is limited to the routine practice of the shop. Another adverse condition is that when the drilling machines are scattered, they cannot always be used to advantage. In one shop a large multiple-spindle drill was standing idle a large part of the time, because there was no work in the department where the machine was installed that could be handled to advantage on it. In the next department work was being drilled on a radial drill that could be handled 400 per cent faster on the multiple drill.

It may be objected that some of the holes in various machine elements cannot be drilled until part of the assembling operations are completed, and for this reason it is an advantage to have the drills in the assembling department; but with a proper system of laying out the work, or by the use of drill jigs, all holes that are drilled by a stationary machine can be drilled before any assembling operations are started. All other drilling will permit of being handled more economically by portable air or electric drills. This laying out never should be performed by the assemblers or the drill hands. The economy of having this work done by men set apart for that purpose is due to several reasons. Men become expert and quick at this kind of work; the drills are not idle while the drill hands stop the machine to do the laying out; besides, it can be done on a convenient plate with proper tools, to better advantage than otherwise. These men can also act as inspectors.

In brief, the worst "time wasters" may be classified as follows:

1. Waiting for a new job or because of lack of proper handling facilities. Result, the machine is idle.

2. Measuring up jig bushings to find out what tools are needed. Result, the machine is idle.

3. Getting tools, clamps, jigs, etc., from the tool supply room for a new job. Result, the machine is idle.

4. Excessive time in "setting up" a job, due to lack of suitable fixtures for holding the work, or lack of proper instructions as to the best method. Result, the machine is idle.

Add to these the loss through failure to use the very best speed and feed for the drills and the result is an output far below maximum efficiency. The important consideration is *time*. Time of the workmen running the drills continuously and efficiently — that is the vital point.

Having these usual defects in system and processes clearly in mind and logically grouped for study, we can easily see the advantages to be gained by having a separate department for the drilling, rigidly supervised by a competent foreman and assistants.

Requirements of an Efficient Drilling Department. — The drilling department preferably should be located between the machine and the assembling departments for convenience in routing the work. A proper arrangement of the drilling machines will depend on the character of the work, type of drive, etc., so that no definite plan can be stated which would be generally applicable. It is the general practice to group the machines according to their size and type.

Boring operations are so closely associated with those of drilling that the boring machines are frequently placed in the drilling department. In fact, in many instances boring can profitably be performed on the less expensive drilling machines, especially when boring jigs are used.

The problem of running the drills at the proper speed and feed will be greatly simplified by providing each machine with brass speed and feed index plates. These furnish the drill hands with a standard guide and eliminate all guesswork. A judicious use of the data presented in Table II will show surprising results.

The equipment for each drilling machine should consist of an abundance of bolts, straps, adjustable blocking, and other necessary fixtures for quickly "setting up" a job. Work chucks will enable the small work to be clamped very quickly. While this factor of "setting up" is far removed from the single problem of drilling, it requires a most vital part of the time required to complete a job. The individual equipment should consist of the necessary sockets, bushings, tapping fixtures, wrenches, and drifts. The machine number should be stamped on its equipment and a suitable cupboard provided in which to keep the outfit. Suitable work-stands are needed for the smaller machines and these should be placed within easy reach of the workmen. For cleaning the chips out of deep holes, a small brass tube fitted with a valve and a dust shield and connected to the air line by a hose is very useful to have by each machine.

The question of handling heavy work under a drilling machine often becomes quite a problem. For this class of work it will always pay to have good hoisting and handling facilities over each machine. These may take the form of compressed air hoists or an overhead single track carrying an electric hoist serving a number of machines — a very economical arrangement. Of course, where the size of work will warrant it, an overhead electric traveling crane of the bridge type is to be preferred. For handling heavy work under a multiple-spindle drill not provided with a work-table on wheels, a specially designed jib crane is needed on account of not being able to reach the center of the table with an overhead crane. This arrangement will permit of handling a number of pieces by the jib crane after the work has been placed within its radius.

Drill and boring jigs will, of course, save the expense of having to lay out the work, but where these are not used it is necessary to provide suitable surface plates. Naturally, these will be located near the receiving point for the work so that the work will be laid out before it is sent to the drills. A surface plate with two surfaces, one at right angles to the other, is very convenient, and will enable center-lines to be drawn from surfaces at right angles without having to move the work. It may be advantageous to have a style of plate that is not a permanent fixture in any one place, and hence can easily be moved from one part of the shop to another. Ample provision is needed for handling heavy work on these plates.

Tool Supply. — If the main tool supply room is not convenient to the drilling department, it will pay to institute a separate tool supply room in this department for the purpose of keeping all the tools, jigs, etc., used by the drill hands. A system should be established for taking care of the tools and jigs, keeping them in good condition, and checking up the workmen in regard to the tools in their possession. Some simple system of checking up the men when returning old or broken tools should be kept. This will enable the foreman to locate his careless workmen. The item of broken tools can become a very large one if the workmen find that little attention is paid to this matter.

It is the practice in some shops to supply and keep a separate outfit of tools with each jig. This is an excellent plan, but one that cannot always be considered on account of the great expense involved. However, when the tools are in any sense special, such as boring-bars, cutters, special reamers, or taps, they always should be kept with the jig to which they belong. A card index of the jigs will be found very convenient. The specimen card shown in the illustration gives an idea of the data required. The cards are indexed according to the forging and pattern numbers. Jig numbers should appear on all detail drawings. The need for an automatic drill grinder has already been pointed out.

Finally, it is necessary to bring to each drill hand the work and tools for his next job, *before he is ready for it*, and this presupposes a method of removing the work and the tools when the job is completed. Thus will every duty of the operator be eliminated, except that of running the drills continuously and efficiently.

Piece No. Jig No.
Space No. No. of Loose Pieces
Machine
Used for
Drawing No.
Used on
Tools used

Form of Jig Index Card

Human Element and Wage Systems. — A chapter on drilling department efficiency would not be complete unless mention were made of the human element and the effect of wage systems on the cost of production. Owing to the simple character of drilling operations and especially when drill jigs are used, it is the custom to have apprentice boys run the smaller machines and to employ drill hands, who are handy men, to run the heavier machines. Any foreman who has "been through the mill" will at once recognize the difficulty of securing proper results from these "drill hands," who have been used to the gait of the average shop, especially if they have been accustomed to using the old carbon-steel drills. The best results are often obtained by securing "green men," who are intelligent and active, and training them properly for the work. In this connection the drilling tables and speed and feed index plates mentioned previously will be found especially valuable.

The system of pay and character of the reward will depend upon the nature of the work and the method of pay already in use. The principle of extra bonus or the attainment of standard time can easily be applied to almost any system of pay. The determination of standard time should be made carefully, however. If the rates have to allow for the adverse influences detailed under the subject of "Causes of Lost Time," the firm will be grossly deceived as to the proper output. A proper discussion of wage systems is, however, too broad a subject to be fully outlined here. Suffice it to say that the workmen must receive a substantial increase in pay for accomplishing the very desirable results which can be secured, if permanent results are expected.

Summary. — Summarizing the elements that enter into the problem of rapid drilling we have:

1. *The drilling machines.*

These must be of a type suitable for the work and must have ample driving power and possess sufficient rigidity; the best type of drive is with a direct-connected variable-speed motor located near the base; the bearings should be self-oiling, and ball thrust bearings should be provided for the spindle; provision should be made for using an abundant supply of lubricant on the drill when drilling steel; there should be a friction drive for rapid power traverse of head on multiple-spindle machines and T-slots in the table of multiple-spindle machines so as to permit clamping the work.

2. *The cutting tools.*

High-speed steel drills and cutters are necessary; these must be run so as to secure a maximum output with a minimum expense for grinding; cooling agents are necessary for steel; sockets for driving tools with broken or twisted tangs are valuable; safety tapping devices are needed; improvement in rose reamers to prolong life of reamer is desirable; drill jigs are an important factor in reducing drilling costs.

3. *The drilling department.*

There is an advantage in having a separate department; machines should be equipped with speed and feed plates; each machine should have its own equipment of fixtures; ample handling facilities are needed; suitable surface plates and men to lay out the work are necessary; it is essential to have a tool supply room in the drilling department, and a system for keeping the tools and jigs and giving out the work is needed; the machines should be kept running continuously and efficiently.

4. *The human element and the wage system.*

Properly trained men are the most efficient; a system of pay is necessary that will reward the extra efforts of the workmen.

CHAPTER VI

DEEP-HOLE DRILLING

The difficulties to be overcome in drilling deep holes may be classified in three groups. In the first place the drill has a great tendency to "run out," thus producing a hole that is neither straight nor uniform in diameter; in the second place great difficulties are encountered in trying to remove the chips in a satisfactory manner, and in the third place the heating of the cutting tool is difficult to prevent.

Methods used for Drilling Deep Holes. — The principle involved in common drill presses where the drill is given a rotary motion simultaneously with the forward motion for feeding is not as well adapted to the production of a straight and true hole as when only a rotary motion is given to the drill and the work is fed toward it. It has been found, however, that for drilling deep holes, the reversal of this, that is, imparting a rotary motion to the work and a feed motion to the drill, will answer the purpose still better. It seems as if there could be no material difference between the two latter methods. An analysis of the conditions involved will show, however, that there is a decided difference in the action of the drill.

If the drill rotates, and the work is fed forward as shown to the left in Fig. 1, the drill, when deviating from its true course, will be caused to increase its deviation still more, by the wedge action of the part *B*, which tends to move in the direction *BA* when the work is fed forward. In the case of the work rotating and the drill being fed forward, as shown to the right, the point of the drill when not running true will be carried around by the work in a circle with the radius *a*, thus tending to bend the drill in various directions. The drill is by this action forced back into the course of "least resistance," as it is evident that the bending action, being exerted on the drill in all directions, will tend to carry the point back to the axis of the work where there will be no bending action. The chips, as is well known, are carried off by forcing a fluid into the hole, which upon its return carries with it the chips. This fluid will serve the double purpose of carrying away the chips and lubricating the cutting tool, keeping it at a normal temperature.

The process of drilling deep holes in metal is a familiar one in many shops, particularly where firearms are manufactured or heavy ordnance is constructed. Since the adoption of hollow spindles for lathes and other machine tools, the methods for machining the bores of guns have been employed in machine tool shops for drilling these spindles; and through this and other means the principles of the operation have become better understood. It is not an easy matter, however, even with the best appliances, to drill or bore a deep hole smooth and round, of exactly the required diameter from end to end, and perfectly straight.

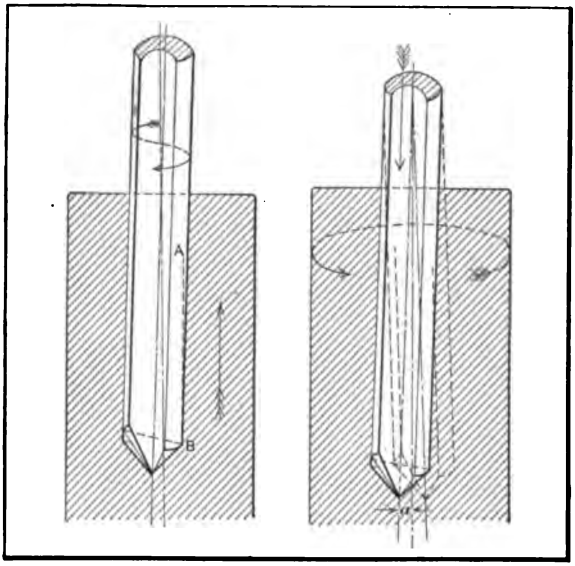


Fig. 1. Principle of Action when Drill and when Work Revolves

It is well known that a long, or deep, hole — that is, one long in proportion to its diameter — is best roughed out and finished by using a tool on the end of a long bar which enters the work from one end. This is true, whether drilling into solid metal or boring and reaming a hole that has already been drilled or bored out. A boring-bar which extends through the piece, and on which is either a stationary or a traveling head, is not satisfactory for very long work, owing to the spring and deflection of the bar, which is made worse by the fact that the bar must be enough smaller than the bore to allow room for the cutter head. While a long hole may sometimes be finished satisfactorily by means of such a boring-bar, by packing the cutter head with wooden blocks which just fill the part of the bore that has been machined, and so support the bar, the method is fundamentally incorrect for long work.

The best methods for machining deep holes are nothing more nor less than an adaptation of what has been found successful in ordinary drilling and boring in the engine lathe or chucking machine. We will, therefore, first discuss certain types of chucking tools and drills and show their relationship to tools that may be used for deep-hole drilling.

General Principles of Deep-hole Drilling. — To start with first principles, consider the ordinary flat drill. It is useful for rough work or in drilling hard metals, because it can easily be made and tempered. When a flat drill runs into a blow-hole or strikes a hard spot, however, it is deflected, the only resistance to this deflection being the narrow edges of the drill. Under such conditions the hole will be out of round and crooked. Add to this natural tendency of a flat drill to run out the fact that such drills are often carelessly made, and one understands why they have a reputation for poor work. Thus, if the point is not in line with the axis of the drill, and if the lips are of unequal length, or do not make equal angles with the axis, the hole will be larger than the drill diameter. The tendency of the drill is to rotate about its point, and thus the axis will move in a small circle about this point, causing the hole to be of larger diameter than the drill.

It is obvious that to improve the action of a flat drill, it should be so guided as to prevent its wabbling and to compel it to move forward in a straight line. This is partially accomplished with the flat chucking drill, which is a near relative of the ordinary flat drill, differing from it in that it is generally more carefully made and is adapted for use in the engine lathe. Fig. 2 is an illustration of a chucking drill at work on a piece in the lathe. For the purpose of illustration it is shown with one lip longer than the other. The work is held in the lathe chuck and turns with the spindle. A rest steadies the drill at a point near the work, and, in starting the hole, the drill is held firmly against the rest by means of a monkey wrench. It will be noted that while a poorly ground chucking drill will make a large hole, like an ordinary flat drill, if properly started it will not wabble, and it will drill the hole where it is wanted and approximately in line with the lathe centers.

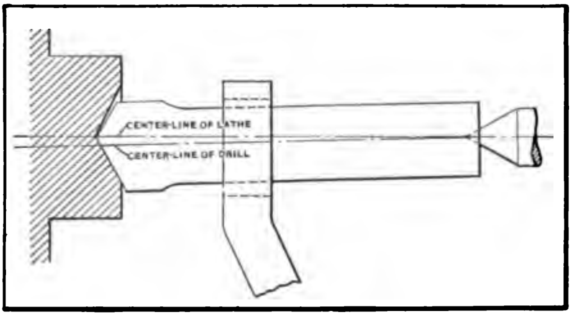


Fig. 2. Action of Improperly Ground Chucking Drill

To attain these results, however, the drill must be started right. If it is found to wabble when left free, it must be started over again, before the full size of the hole has been cut, by crowding it so that only one edge of the drill cuts. This edge will then true up the hole, and in proceeding with the drilling the trued hole will guide the drill. The latter will thus be continuously supported near the cutting edges by the cylindrical surface of the hole, and the drill will tend to advance in the direction in which it was started. For reasons that will be explained, the flat drill is not an accurate tool, even when well made and used in the lathe, and the flat reamer is not as reliable as one with more blades. The general principle, however, of first starting with a true hole, and then having the drill body designed to follow in its path and so guide the cutting edges, is the fundamental principle of deep-hole drilling.

Fig. 3 shows how a flat drill may be adapted for deep-hole drilling. The drill from which the illustration was made was employed for drilling a four-inch hole through steel rolls seven feet long. Instead of depending upon the narrow edges of the drill proper to guide and support the cutting edges, the cutting edges are formed on a blade inserted in a cylindrical cast-iron head, the outside diameter of which is turned to a sliding fit in the hole that is being bored. The cutting edges are grooved to break up the chips, enabling the latter to pass out through the passage *E*, on each side of the head. The grooves are laid out so that those in one blade come opposite the lands in the other blade. In the illustration, *A* is the cutter, *B* one of the screws holding the cutter to the head *C*, and the head is attached to the bar by the shank *D*.

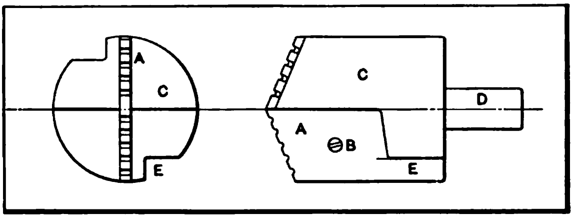


Fig. 3. Drill with Inserted Blade for Deep-hole Drilling

Twist Drill for Deep Holes. — The modern twist drill accomplishes all that is attained by the drill shown in Fig. 3, and can, in addition, be ground without seriously affecting the rake, and will free itself from chips more readily, owing to its spiral flutes. The lands of a twist drill present a large cylindrical surface to bear against the sides of the hole and take the side thrust. If the drill is also guided by a hardened bushing, at the point where it enters the metal, as in the case of jig work, the drill will have very little chance to deflect, and the hole will be accurately located and will be quite true and straight.

The twist drill in a modified form is also employed for deep-hole drilling. The hollow drill introduced by the Morse Twist

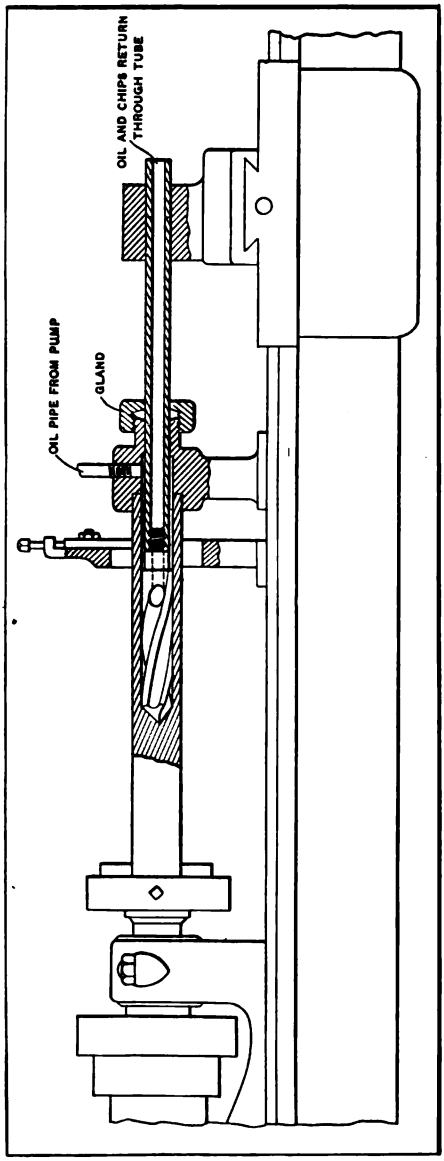


Fig. 4. Arrangement of Machine when Drilling Deep Holes with Hollow Twist Drill

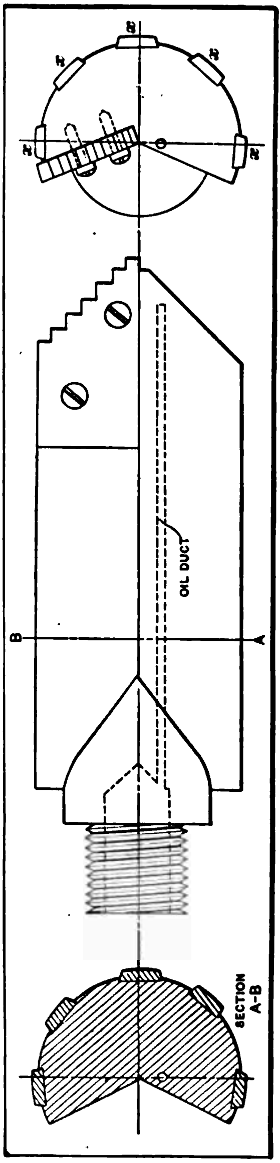


Fig. 5. D-drill with Inserted Blade, used for Deep-hole Drilling; Pieces x are Hardened Steel Strips, Dovetailed in Place and Ground to Size

Drill Co. is adapted for this purpose, and in Fig. 4 is shown the arrangement for feeding this drill into the work. The drill has a hole lengthwise through the shank, connecting with the grooves in the drill, as indicated. The shank can be threaded and fitted to a metal tube which acts as a boring-bar and through which the chips and oil may pass from the point of the drill. Oil is conveyed through a pipe to the outside of the tube, as shown in the illustration.

In using the hollow drill, the hole is first started by means of a short drill of the size of the hole desired, and drilled to a depth equal to the length of the hollow drill to be employed. The body of the hollow drill acts as a piston, compelling the oil to follow the oil grooves provided and the chips to flow out through the flutes and the hollow shank. The methods of supporting and driving the work and of feeding the drill are clearly shown. Drills of this type are regularly manufactured in sizes up to three inches in diameter, and it is stated that the best results are obtained, when drilling tool steel, by revolving the drill at a cutting speed of 20 feet per minute, with a feed of 0.0025 inch per revolution, while machine steel will admit of a cutting speed of 40 feet per minute and a feed of 0.0035 inch per revolution.

Number of Cutting Edges. — When drilling a hole out of solid stock, some type of drill having two lips or cutting edges is usually the most feasible, and probably nothing will be devised that on the whole surpasses the twist drill for such work. As is well known, the ordinary twist drill is always provided with two flutes, but twist drills having three or more flutes have been devised, made, and tried. The advantages gained by adding to the number of cutting edges have, however, not been great enough to justify the increased cost of manufacture. An end-mill can be used for drilling, if it has a "center cut," and it will presently be explained how a tool with a single cutting edge may be advantageously employed, particularly for deep-hole drilling. The familiar D-drill is of this type, and also its modification as used by the Pratt & Whitney Co. in drilling gun barrels.

When it comes to truing up or enlarging a hole previously drilled or bored, the two-lip drill is not suitable in any of its forms. For boring a true hole nothing can surpass a single-pointed boring tool. It is obvious that when a hard or soft spot is encountered in boring with a tool having a single cutting edge, only that particular place is affected by the spring of the tool; with a double cutter, as shown at *A*, Fig. 6, any deflection due to irregularities, such as at *a* or *b*, will cause the tool to spring and the cutting edge on the opposite side to introduce similar irregularities in the opposite side of the hole. This is one objection to the two-lip drill for accurate work.

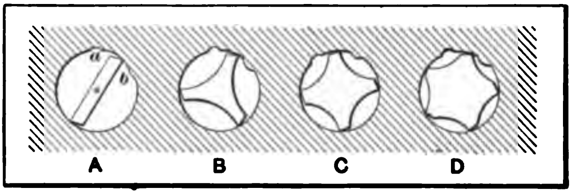


Fig. 6. Diagram Illustrating the Effect of the Number of Cutting Edges

With three points the tool is somewhat better supported when a high place is encountered, as shown in sketch *B*, and when a cutting point strikes a low place the other two edges are not moved away from their position so much as if they were opposite the first edge; hence a tool with three edges should prove better than one with two, and one with four, being better supported, would seem better on this account than one with three, but has

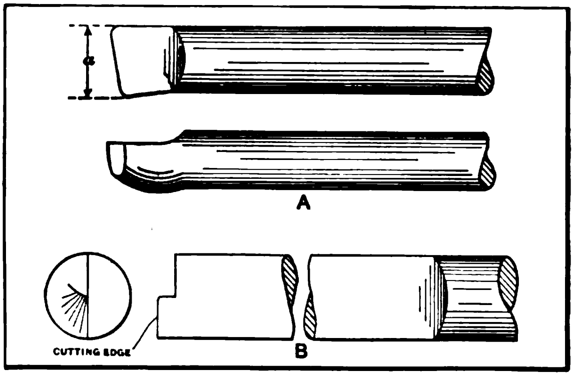


Fig. 7. (A) End-cutting Boring Tool; (B) D-drill used for Deep-hole Drilling

the disadvantage of opposite cutters. Five edges ought to give still better results.

In general, it may be said that in boring the best results are obtained when the tool has a single cutting edge, but if it is desirable to have more cutting edges, a tool with several will be more satisfactory than one with only two. Any machinist who has tried to true up the taper hole in a lathe spindle, first by boring and then by reaming, will appreciate the superiority of the boring tool over the multi-blade reamer. A reamer sometimes refuses to produce a perfectly round hole, and will do this whether the number of teeth is odd or even.

Advantages of the End Cut. — One trouble with reamers is that the teeth necessarily cut on their side edges instead of on their ends, and the whole effect of any unevenness in the hole is to crowd the reamer to one side. The condition exists to a less extent with a flat or twist drill, where the cutting edges are at an angle with the center-line, and the resultant of any unusual pressure is felt partly as a side thrust and partly as an end thrust. Now, by making a drill to cut squarely on its end and but very little, or not at all, on its sides, the side thrust is mostly done away with. The end-mill is a good illustration of such a tool, and it is known to be capable of boring very accurate holes when used for that purpose in the milling machine.

At *A* in Fig. 7 is shown a boring tool with a single cutting edge, which cuts on its end and is capable of drilling a true hole in solid metal. It consists of a round tool steel bar, with one end flattened and ground to form a cutting edge, as shown. It is designed to be held in the toolpost of the lathe, in a position perpendicular to the faceplate. The inner edge or corner of the cutting edge should be slightly rounded to help support the cutter and prevent chattering, and the width of the cutting edge should be from $\frac{1}{32}$ to $\frac{1}{16}$ inch less than the radius of the hole to be drilled. The objection to this tool is that it cannot be supported stiffly enough by the toolpost for a hole of great depth, and for this purpose the D-drill shown at *B*, which works on the same principle, is preferable. In its simplest form it consists of a round bar of the diameter of the hole to be drilled, one-quarter to one-half of which is milled out to give a passage for the chips. The end of the bar is shaped with a cutting edge on one side, extending nearly or entirely to the center, and with the other side relieved to give clearance for the cutter. Such a drill should be supported by a bearing close to the hole to be bored, in case it is to start the hole itself, and it is better yet to start the hole with a twist drill and true it up with a single-pointed boring tool, and then let the drill be guided by this hole. This is the surest way of getting a hole concentric with the axis of the lathe. As the bar is of the same diameter as the hole, the cutter will be supported by one-half the surface of the hole, and if it is once started right in an accurate hole it will continue in the right direction.

It is desirable to have the cutter blade separated from the bar or head, as the case may be, so that it may be renewed or removed for grinding, particularly in drilling large holes. Fig. 5 shows such a cutter head as used by a large ship- and engine-building concern, for drilling propeller shafts. The body of the cutter is made from soft steel with tool steel strips *x* dovetailed in and ground in place to size. The cutters are made by jigs and are interchangeable, and their shape is such as to break up the chips, which are washed out, by the force of oil supplied by a pump, through the hollow boring-bar, to which this cutter head is fastened. One of these cutters, four inches in diameter, has bored 12 inches in a piece of nickel steel in one hour, cutting a fair and smooth hole, and no trouble has ever occurred, even when holes have been drilled to a depth of 32 feet.

In deep-hole drilling it is customary to have the drill fixed so that it cannot turn and rotate the work, following the usual method in this respect for boring accurate holes in the lathe. Since the outer end of the work can be supported in the center-rest, it is always possible to make the work run true, while it is not so easy to make a drill run true and coincident with the axis of the work. The difference in principle involved has already been explained.

Deep-hole Drilling Attachment. — An attachment is shown in Fig. 8 for performing deep drilling on the engine lathe. This attachment consists essentially of a drill spindle, mounted on the cross-slide in place of the usual toolpost, in combination with an electric motor and suitable gearing for rotating the spindle. A support is provided for holding the outer end of the work, the other end of which is clamped in the chuck or faceplate of the lathe. Provision is also made for forcing a copious supply of lubricant to the point of the drill used. The purpose of the attachment is to make it possible to drill a hole true with the center-line by the usual method of rotating the work, and at the same time to give the high cutting speed of which high-speed tools are capable, without necessitating a high rate of revolution for the heavy spindle and gearing of the lathe.

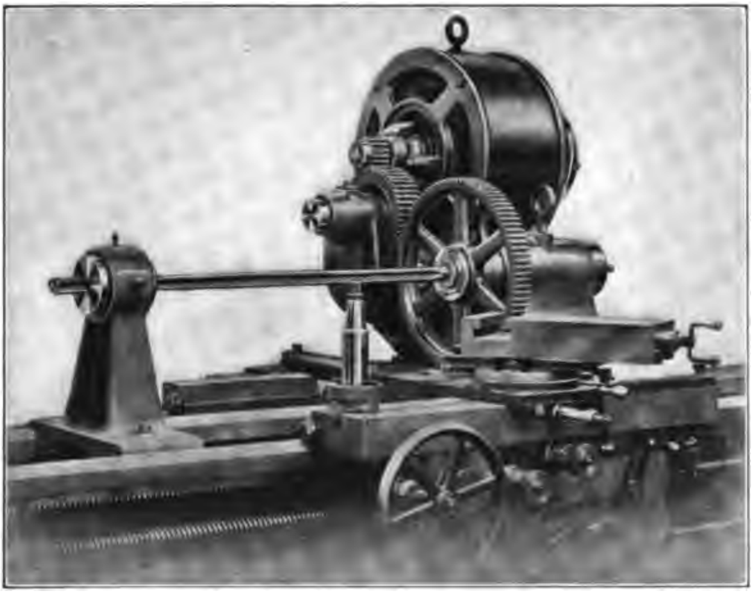


Fig. 8. Lodge & Shipley Motor-driven Attachment for Deep Drilling in the Lathe

The drill spindle bearing, with the bracket on which the motor is mounted, is cast as one piece with the bedplate. This plate is bolted to the wings or arms of the carriage. The 3-horsepower 2 to 1 variable speed motor shown is connected to the drill spindle through an intermediate rawhide gear. The spindle is bored to supply lubrication to the drill and is ring oiled. The drill shank is fitted to the hole in the spindle by reducing bushings.

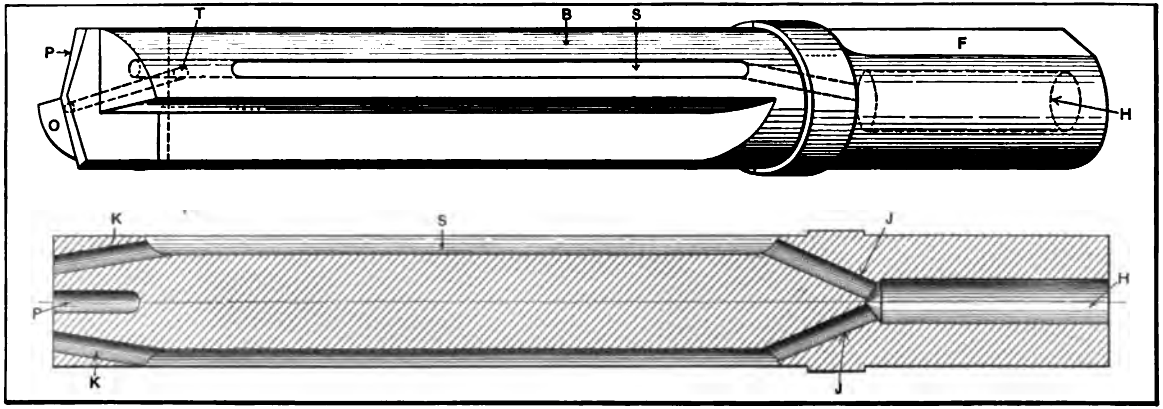


Fig. 9. Sectional and Perspective Views of Deep-hole Drill

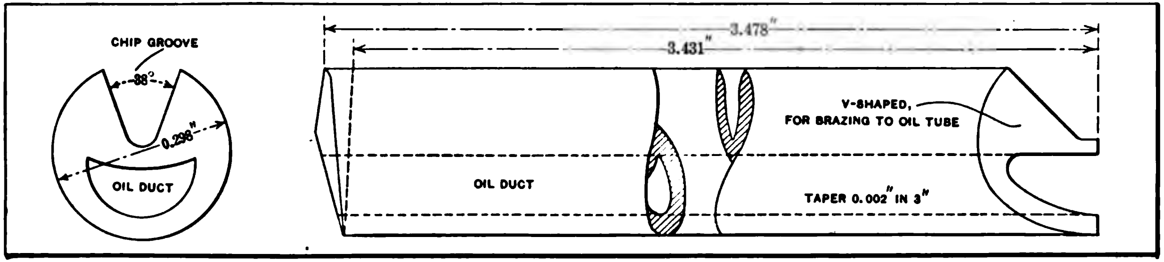


Fig. 10. Detail of Deep-hole Drill, 0.303 inch Diameter, Enlarged about Three Times

The outer end of the drill is carried in a free bushing, revolving in a support bolted to the lathe bed. The drill used is of the special construction known as the "Chard" deep drill (see Fig. 9). A flat blade of high-speed steel is held in position at the end of a steel shank by a tapered pin; it is so ground as to break up the chips and thus facilitate their removal. Lubrication under pressure sufficient to clear the chips and cool the cutting edge is supplied by a pump attached to the lathe at the rear of the headstock and driven from the lathe countershaft. Flexible tubing connects this pump with the hollow spindle. Two copper tubes, flush with the surface of the drill, carry the lubricant to the cutting edge. This type of drill has been used for drilling lathe spindles, back-gear sleeves, and pulley sleeves and for drilling holes in locomotive driving axles, the holes being 1 inch in diameter and 44 inches deep.

Deep-hole Drills. — It has always been an expensive operation to drill out the interior of a hollow spindle. Indeed, it has not only been an expensive operation, but, on account of the spindle being of high-carbon steel, it has also been a difficult operation. Nearly all lathes nowadays must be built with a hollow spindle. This is also true of spindles of boring machines, drill presses, etc., and thus we have a large variety of work on machine tools which involves deep drilling. The cost of deep drilling has been greatly reduced recently, by several manufacturers, by the use of special deep-hole drills. A strong flow of oil is forced through the drill against the cut, and on its return carries the chips with it, thus performing the double function of keeping the drill cool and clearing out the chips.

One of these drills fitted up complete for work is shown in Fig. 9. This drill was developed in the shops of the Lodge & Shipley Machine Tool Co., by N. D. Chard. The body of the drill *B* is made of machine steel. The point *P* is made of tool steel and is held in position by the taper pin *T*. A hole *H* is drilled in the shank, and from this hole the oil is led to slots *S*, which are milled along the outside. These slots run the full length of the drill and then shoot down at the ends, as indicated. *F* is a flat spot for holding the drill.

The longitudinal sectional view of the drill shows the passageway for the oil. Two small holes *J* are drilled into inlet hole *H*. The holes *K* are then drilled, and a piece of brass tube is bent in the arc of a circle and the ends are entered into the holes *J* and *K*. The tube is then hammered down into place, and the joint is flushed with solder. The slot *P* is milled out so as to have a semi-circular bottom. Into this slot the cutter or point of the drill is neatly fitted. These points are made of high-speed steel. The shape is illustrated in Fig. 11. The hole *H* in the cutter is reamed through the drill, while the cutter is clamped firmly back against its seat at the end of the slot. The angle *A* is made about 20 degrees. The cutting edge is nicked at several places, as at *N*, in order to break up the chips, this being done on the corner of an emery wheel. After the drill is put into place, it is ground up accurately to the diameter *D*.

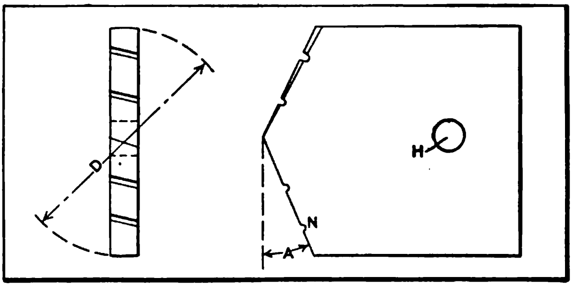


Fig. 11. Blade of Deep-hole Drill shown in Fig. 9

The arrangement of a turret machine for boring out lathe spindles with this drill is shown in the illustration in Fig. 12. Instead of the long slide and hexagonal turret, a special slide *A* is provided, which receives the drills. *B* is a steadyrest and *S* is the spindle. A lathe carrier is screwed onto the end of the spindle, as shown, and a plate *P* holds the spindle up against the center by means of a few bolts. At *C* is shown a small pump which gives an ample supply of oil. A flexible tube leads from the pump to the fitting *F*, and from thence the oil enters the spindle. The trays *T* catch the oil, and from these trays a pipe leads to the suction side of the pump. The drill is made long enough so as to run a short distance beyond the middle of the

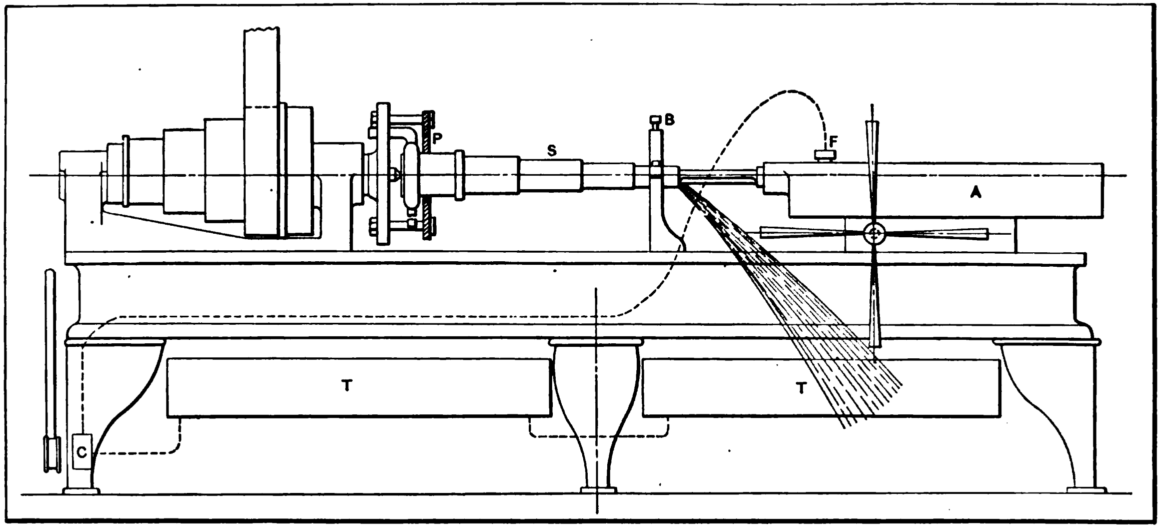


Fig. 12. Turret Lathe Arranged for Deep-hole Drilling

spindle to be drilled, the spindle being then turned around and drilled from the other end. With a drill made up in the manner explained, it is possible to drill a $1\frac{5}{16}$ diameter hole in a 0.40 carbon steel spindle at the rate of $1\frac{3}{8}$ inch per minute. The cutting speed would be 60 feet per minute at the largest diameter of the drill.

The type of drill shown in Fig. 10 differs in some essentials from the types already referred to. In the factory where it is used, an ordinary micrometer is used for gaging it, the end of the measuring point on the micrometer spindle being pointed a little less than the included angle of the groove in the drill, which is about 38 degrees. This type of deep-hole drill is far superior to the old drill with round oil hole, it being cheaper to make; at the same time, the crescent-shaped hole allows a greater flow of oil at the cutting edge.

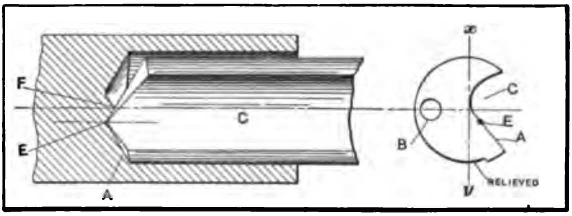


Fig. 13. Deep-hole Drill Especially adapted for Drilling Rifle Barrels

Drill for Rifle Barrels. — A highly satisfactory drill for use in drilling deep holes is one brought out by the Pratt & Whitney Co., principally for use in connection with their rifle-barrel drilling machines. The tool in question is a development of the old D- or hog-nose drill, already described, which has one cutting lip only. It is carefully ground on the outside and is supplied with an oil duct through which oil at high pressure may be brought directly to the cutting edge.

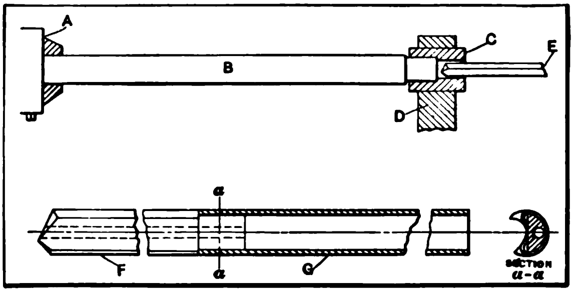


Fig. 14. Arrangement for Starting the Deep-hole Drill, and Method of Fastening Shank to Drill

Referring to Fig. 13, *A* is the cutting edge, *B* the oil duct, and *C* the chip groove. In milling the latter groove, the cutter is brought directly to the center-line, so that in this respect the drill is very free-cutting as compared with the ordinary two-lip twist drill which has a central web. In the end view, the shape of the chip groove is clearly indicated. The cutting edge *A* is radial. The high point *E* or part first entering the work is not in the center as is usually the case in drills, but to one side as shown. Grinding the drill in this manner makes possible its running true or straight, the teat *F* on the work acting as a support to the drill, which, owing to its periphery being partly relieved, would have a tendency to travel in a curve away from its cutting side. The piece being drilled is run at very high speed, the peripheral speed at the outer diameter of the hole being as high as 130 feet per minute on machine steel. The feed, however, is quite fine, on a 0.3-inch drill averaging 0.0004 inch per revolution, while on a 3-inch drill it is about 0.0008 inch. These figures, of course, are dependent to a great extent on the material being drilled. The drills are made of high-grade steel and left very hard, so that the fine feed has little tendency to glaze the cutting edge.

The piece being drilled is held and revolved at one end by a suitable chuck on the live spindle of the machine, while the other end, which should be turned perfectly true, runs in a stationary bushing having at its outer end a hole the diameter of the drill. The drill enters the work through the bushing and is thus started perfectly true. The arrangement is indicated in the upper view in Fig. 14, in which *A* represents the chuck, *B* the work, *C* the bushing, *D* the support for holding the bushing, and *E* the drill. Through the oil duct of the drill, oil is forced at a pressure varying from 150 to 200 pounds per square inch. After passing the cutting edge, the oil returns to the reservoir by way of the chip groove, forcing the chips along in its travel. In drills of large diameter, especially when working on tough, stringy material, the cutting edge is usually ground so as to produce a number of shavings, instead of one the full width of the cutting lip, so that no trouble is experienced in getting chips out of the way. The oil, of course, is used over and over again, and with a large reservoir will be kept quite cool.

The drill is made up of the drill tip and shank, the tip varying in length from 4 inches to 8 inches, while the length of shank is determined by the depth of hole that is to be drilled. The lower view in Fig. 14 illustrates the construction of a small, complete drill, *F* being the tip, and *G* the shank. The shanks on small drills are made from steel tubing, rolled as shown in the cross-section at the right-hand end. The tip is carefully fitted and soldered to the shank, which, it should be noted, is a little smaller in diameter than the tip.

The relief or clearance of the cutting edge of the drill, the amount the "high point" of the drill should be off center, and the number of rings on the end of the drill, when provided with notches for breaking up the chips, depend entirely upon the material that is to be drilled. For instance, on very soft stock, the supporting teat should be more substantial than on hard spindle or gun steel, so that it is evident that on soft stock the high point should be more off center, or nearer to the outer diameter, than on hard stock. Fig. 15 shows how a drill is ground on the end so as to produce several shavings.

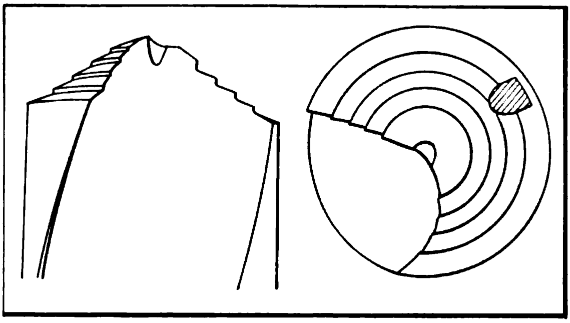


Fig. 15. Side and End View of Deep-hole Drill

The method of relieving large drills is shown at *C*, Fig. 16. The straight or radial edge is the cutting edge of the drill and the distance x is about $\frac{1}{8}$ inch on a one-inch drill. The surface y is left to the full radius of the drill and makes a good back-rest. When the drill is ground on its periphery, it is made very slightly tapering toward the shank to free itself. As previously stated, in milling the chip groove the cutter is brought exactly to the center of the drill. When hardening and grinding, however, the location frequently changes slightly so that the groove does not come to the center of the drill. In such cases it is necessary to grind out the lip at the point as shown in Fig. 15. Generally the operator grinds a little beyond the center, but no trouble results, as the small teat produced thereby is broken off when the bottom of the ground out place comes in contact with the end of the teat, as indicated at *A* in Fig. 16.

The tube and gun-barrel drilling machine, built by the Pratt & Whitney Co., while primarily designed for drilling gun barrels, is adapted for any class of deep-hole drilling, such as hollow spindles, etc. The machine is provided with a double head, the heads being placed side by side at one end; independent spindles are mounted in each head. On their inner ends are chucks for securing and rotating the work, which is also supported by split bushings carried in rests on the bed. The drills are carried by the carriages and fed positively by power feed. This feed is variable, to provide for different qualities of stock to be drilled. Two rotary pumps, one for each head, force oil, supplied from a tank placed underneath the machine, through a series of tubes into and through the drill. The oil lubricates the cutting lip and forces out the chips into the basin on the top of the tank, where they are drained and from where the strained oil is returned to the tank again.

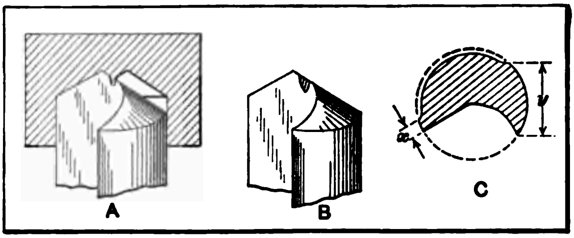


Fig. 16. Cutting Ends of Deep-hole Drills

Use of Compressed Air for Deep-hole Drilling. — It is generally recognized that compressed air can be used as a cooling medium for drilling cast iron, but there are few mechanics who would advocate its use for machine steel. It may be interesting, therefore, to record an application of compressed air to deep-hole drilling in machine steel. In the plant of an automobile manufacturer a piston pin made from round bar stock containing from 0.20 to 0.30 per cent carbon is drilled by using compressed air as a cooling medium instead of a lubricant. The pin is 5 inches long and the drilled hole $\frac{5}{8}$ inch in diameter. This piston pin is machined in an automatic screw machine which is fitted up with the regular oil feed arrangement for the turret tools, but instead of forcing oil through the piping, compressed air of 75 pounds gage pressure is used.

The drill used is a regular fluted high-speed steel, oil-tube drill, ground on the cutting edges so as to break up the chips. A long curling chip would be difficult to remove, as it would twist around the flutes of the drill. The drill is not withdrawn from the work until it has been forced in the desired distance, or 5 inches, at a steady feed of 0.015 inch per revolution and a surface speed of about 70 feet per minute.

The chips which are blown out by the compressed air are quite cool and can easily be held in the hand. The hole produced is smooth as compared with that obtained when oil is used as a lubricant. A good grade of lard oil was used on this job before compressed air was tried, but the oil proved unsatisfactory as the drill would bind and heat up before the lubricant reached the bottom of the hole. It seems that the oil made the chips adhere to each other and thus prevented them from being washed out of the hole; on the other hand when the chips are kept clean and cool by the compressed air they are blown out just as soon as they are removed by the drill.

Deep-hole Drilling in Gun Construction. — The introduction of built-up or hooped guns necessitated many new designs and radical changes in machine tools, especially in the lathe. In the following, some of the methods and tools developed for deep horizontal boring and reaming in the roughing and finish-boring of the tubes for modern built-up steel guns, will be referred to. These tubes, which constitute the central portion of the guns, and upon which a series of hoops are shrunk, are made of a very high quality of special oil-tempered steel. The tubes, according to requirements for the various sizes of guns, usually vary in length from 20 to 50 feet, with internal diameters from 6 to 30 inches, for the large guns, and from 5 to 15 feet in length, with internal diameters from 3 to 6 inches, for the smaller sizes.

As it is primarily essential that the bore of these tubes be perfectly straight and the diameter correct and uniform, it might be of interest to point out the simplicity of design and performance of the tools with which this most important operation is performed. The forgings for the tubes as received from the steel works have a surplus amount of metal on the inside and outside, to allow for the boring and turning operations. Owing to the length being so great in comparison with the diameter, they are also, in the majority of cases, more or less warped, due to the processes of oil-tempering and annealing to which they have been subjected. After having ascertained the amount of existing warp and having investigated the concentricity of the inner and outer circumferences, the tube is centered and spotted in a special lathe designated for the purpose, preparatory to the first rough-boring. The tool used in rough-boring, commonly known as a "hog-nose" tool, and represented in Fig. 17, consists of a semi-circular cast-iron body provided with a shank on one end for securing it to the front end of the boring-bar. The cutter *C* is made with the edge cutting square on the forward end, and with the lip turned slightly upward, in order to roll the chips backward. (See detail view in upper right-hand corner.)

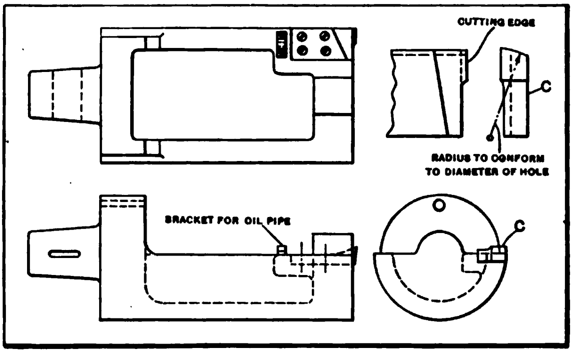


Fig. 17. Hog-nose Tool Boring Head

Provision is made to throw a jet of a lubricating mixture in front of the tools during the operations of boring, reaming, and finishing, the lubricant serving to diminish the friction on the tools as well as to preserve their temper. This is accomplished by a rotary oil pump which conveys a continuous stream of oil

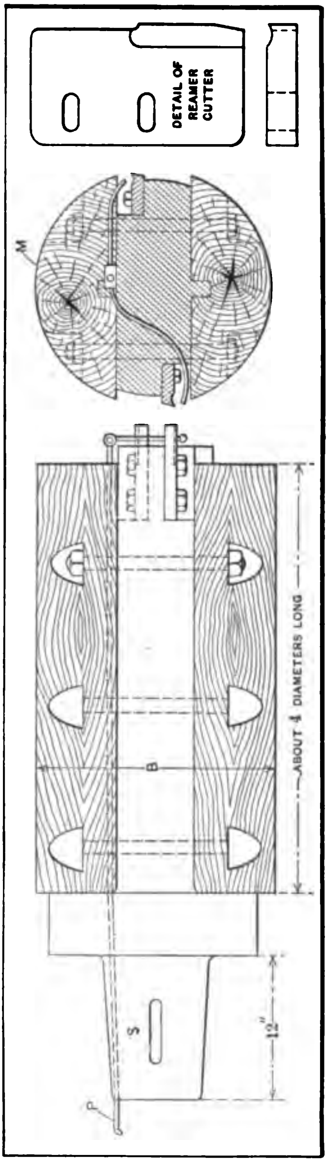


Fig. 18. Tool for Finishing and Reaming Holes in Large Guns

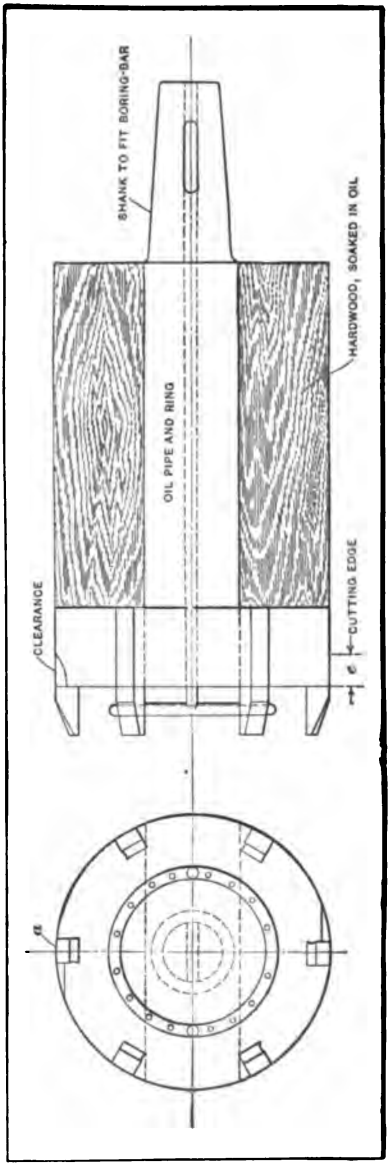


Fig. 19. Boring Tool for Holes of from Three to Six Inches in Diameter

by means of two wrought-iron pipes connected with an intermediate flexible metallic hose which travels with the boring-bar and is attached to a fixed pipe which passes through the interior of the boring-bar, terminating at the end of the cutting tools. The pump is provided with different changes of speed. Although this tool (Fig. 17), because of its design, is capable of removing a considerable quantity of metal, ordinarily it should not remove more than from 0.2 to 0.5 inch of metal on the side, leaving approximately 0.01 inch to be removed by the reaming and finishing tool in the succeeding operations.

The rough-boring being completed, the hog-nosed tool is removed, and the tool shown in Fig. 18, for finishing and reaming, is inserted in its place. This tool has a cast-iron body and a length equal to about four diameters. To the body are bolted two semi-circular blocks of carefully selected and well-seasoned oak or maple that have been previously submerged for a long period in a bath of lard oil and that serve as guides for the cutters bolted to the front end of the head. These blocks, while in position, are turned off to a diameter about 0.005 inch larger than the desired bore, the idea being to force them in and thus give them a smooth and uniform bearing surface. The cutters used are made from a very high-grade steel, ground to exact size, and oil-stoned to conform to the required diameters.

To insure a perfect alignment for the tool before commencing the actual reaming, it is good practice to counterbore the tubes from 3 to 6 inches deep. The method of supplying oil while reaming is the same as employed in the operation of rough-boring. It may be of interest to note that, with the same cutting speed, the feed may be from four to five times that of the feed for the hog-nosed tool. The cutter is given a taper in front of about 1 to 10, with a straight cutting edge 1 inch long on the side. (See detail of reamer cutter.) Such construction also serves to maintain the size in case the forward part of the cutter becomes slightly worn.

Multiple-cutter wood reamers (see Fig. 19) have been successfully used for bores of from 3- to 6-inch caliber and for lengths varying from 5 to 15 feet. Greater feed can be employed with tools thus constructed, and consequently considerable time is saved by their use. It must be borne in mind, however, that in tubes of great length, in which there is an unequal distribution of stock on the interior, these tools have a tendency to run out of their true axis, thus leaving an unsymmetrical bore. This difficulty is obviated and a uniform bore obtained by the use of the previously described hog-nosed tool and wood-lined reamer, although some time is sacrificed owing to the reduced feeds which have to be used, as compared with the feeds obtainable with a multiple-cutter wood reamer.

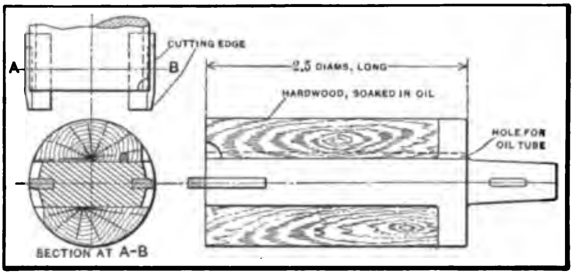


Fig. 20. Finishing Tool for Reaming Holes of from Three to Six Inches in Diameter

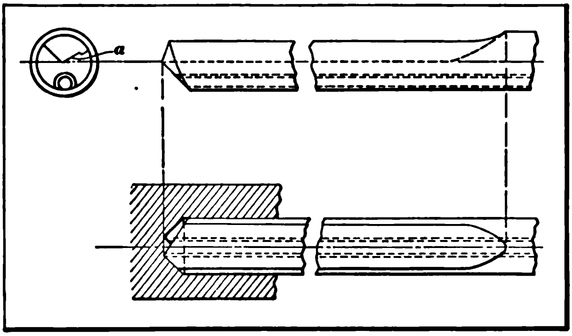


Fig. 21. Type of Deep-hole Drill gaged by Micrometer shown in Fig. 22

In boring guns, lathes are employed which are specially designed for the purpose. Nevertheless, if such a machine is not available, for short lengths and small bores, it is advisable to use the old and well-known method of attaching to the cross-slide of a common lathe of suitable length of bed, a fixed support or bracket having a bore to receive a number of bushes, the bores of which correspond to the varying diameters of boring-bars. The hub of this support or bracket has one side split to enable it to be tightened by a bolt, in order to retain and grip the bushing which is likewise split for the purpose of gripping the boring-bar. The boring and reaming tools shown in the engravings, Figs. 19 and 20, are particularly applicable in this case. After having determined the required feed and set the lathe in motion, the carriage will serve to feed the bar in the usual manner. The other functions are performed in the ordinary way and are too obvious for further explanation.

Micrometer for Deep-hole Drill. — Deep-hole drills of the type shown in Fig. 21 should be made so that the cutting edge or lip *a* of the drill is a radial line, or, in other words, so that it goes exactly through the center of the drill. It is clear that if a drill is made having the cutting edge under the center, a small core of the stock in the center will not be cut off, and will instead tend to remain and form a slender column or thread remaining in the hole. On the other hand, if the cutting edge lies over the center, the center portion cannot be cut out. In deep-hole drilling, this is not permissible, as it will very soon cause inaccuracy of the hole or breaking of the drill. Hence it follows that the location of the cutting edge exactly in the center is very important. A glance at the end view of the drill shows that a direct measuring of the drill center cannot be made with ordinary instruments. Ludwig Loewe & Co., of Berlin, Germany, employ for this purpose a special micrometer by means of which one can determine whether or not the apex of the groove coincides with the center or axis of the drill. This micrometer is shown in Fig. 22. Its construction is the same as that of an ordinary micrometer with a V-point for measuring screw threads, but in addition it has an adjustable V-block which is locked in position by a clamping screw. Two disks 10 and 30 millimeters in diameter, respectively, are provided. The smaller disk is used for setting the micrometer for drills up to 32 millimeters, and the larger one for drills of 30 to 60 millimeters diameter. For measuring drills of small diameter up to 32 millimeters the scale of the micrometer is set to 10.52 millimeters (5 + 5 × 1.1045), and the disk of 10 millimeters diameter is placed in the V-block, after which the block with the disk is pushed against the measuring point and clamped fast in this position, whereupon the preliminary adjustment necessary is completed. For adjusting the micrometer for drills of 30 to 60 millimeters diameter, the 30 millimeters disk is used in the same manner, but the scale of the micrometer in this case is adjusted to 16.56 millimeters (15 × 1.1045). After having found the preliminary adjustment of the V-block for drills up to 32 millimeters diameter, the radius of the drill to be measured is multiplied by the constant 1.1045, and the scale of the micrometer adjusted accordingly. For example, suppose we wish to measure a drill whose radius is 7.45 millimeters. We must find the proper reading for the micrometer screw when the drill is laid in the angle block and the point bears against the groove. The product of 7.45 × 1.1045 = 8.2 millimeters; hence, if, in measuring the drill of 7.45 millimeters radius, we get a micrometer reading of 8.2 millimeters, the apex of the angle of the groove lies exactly in the center of the drill.

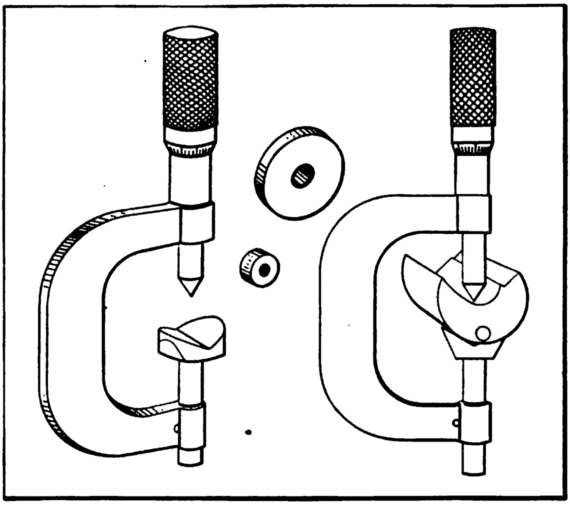


Fig. 22. Special Micrometer for Testing Deep-hole Drills

To adjust the micrometer for drills of from 30 to 60 millimeters diameter, the radius of the drill is multiplied by the constant

1.1045, and 15 millimeters is subtracted from the product, or $r \times 1.1045 - 15$ millimeters = micrometer setting.

The principle of the gage depends upon the proposition that the homologous sides of similar triangles are in direct proportion. Thus at *A*, in Fig. 23, we have $\frac{r}{l} = \frac{r_1}{l_1} = \frac{r_2}{l_2}$, etc. Therefore the values of l_1 and l_2 are easy to determine, since $l = \frac{r}{\sin \alpha}$, in which r corresponds to the radius of the drill and $\alpha = \frac{1}{2}$ the constant angle of the V-block of the micrometer, from whence we derive the constant 1.1045.

It will be observed that the product of the radius by the constant is used directly when setting for drills 32 millimeters or less in diameter, but that when measuring drills of 30 to 60 millimeters diameter the product is diminished by 15 millimeters. This is because in setting to the 30 millimeters disk the micrometer screw is adjusted to 16.56 millimeters, instead of 31.56 millimeters, in order to make the scope of the micrometer include the larger drills without the need of making a larger frame. The principle is illustrated at *B*. For the disk *M* we have $l + r = \frac{r}{\sin \alpha} + r$. Hence, if one sets the screw of the micrometer to this measurement and pushes the V-block, with the disk *M* resting in it, until the disk is found to be in perceptible contact with the measuring point of the screw and there clamps it fast, the gage is adjusted. The proof of the correctness of the setting is that if we put back the micrometer screw equal to $l + r$ then will the point of the screw lie in the vertex of the angle α. In other words, the lengths l, l_1, and l_2 will be exactly indicated without calculation.

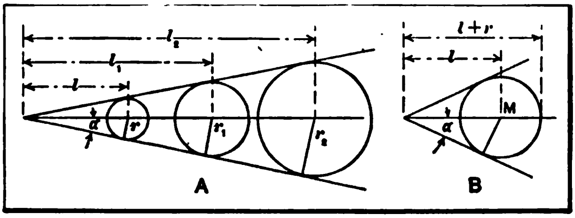


Fig. 23. Diagrams Illustrating Principle of Deep-hole Drill Micrometer

CHAPTER VII

PRINCIPLES OF JIG DESIGN

Jigs and fixtures may be defined as devices used in the manufacture of duplicate parts of machines and intended to make possible interchangeable work at a reduced cost, as compared with the cost of producing each machine detail individually. Jigs and fixtures serve the purpose of holding and properly locating a piece of work while machined, and are provided with necessary appliances for guiding, supporting, setting, and gaging the tools in such a manner that all the work produced in the same jig or fixture will be alike in all respects, even with the employment of unskilled labor. When using the expression "alike," it implies, of course, simply that the pieces will be near enough alike for the purposes for which the work being machined is intended. Thus, for certain classes of work, wider limits of variation will be permissible without affecting the proper use of the piece machined, while in other cases the limits of variation will be so small as to make the expression "perfectly alike" literally true.

Objects of Jigs and Fixtures. — The main object of using jigs and fixtures is the reduction of the cost of machines or machine details made in great numbers. This reduction of cost is obtained in consequence of the increased rapidity with which the machines may be built and the employment of cheaper labor, which is possible when using tools for interchangeable manufacturing. Another object, not less important, is the accuracy with which the work can be produced, making it possible to assemble the pieces produced in jigs without any great amount of fitting in the assembling department, thus also effecting a great saving in this respect. The use of jigs and fixtures practically does away with the fitting, as this expression was understood in the old-time shop; it eliminates cut-and-try methods, and does away with so-called "patch-work" in the production of machinery. It makes it possible to have all the machines built in the shop according to the drawings, a thing which is rather difficult to do if each individual machine in a large lot is built without reference to the other machines in the same lot.

The interchangeability obtained by the use of jigs and fixtures makes it also an easy matter to quickly replace broken or worn-out parts without great additional cost and trouble. When machines are built on the individual plan, it is necessary to fit the part replacing the broken or worn-out piece, in place, involving considerable extra expense, not to mention the delay and the difficulties occasioned thereby.

As mentioned, jigs and fixtures permit the employment of practically unskilled labor. There are many operations in the building of a machine, which, if each machine were built individually, without the use of special tools, would require the work of expert machinists and toolmakers. Special tools, in the form of jigs and fixtures, permit equally good, or, in some cases, even better results to be obtained by a much cheaper class of labor, provided the jigs and fixtures are properly designed and correctly made. Another possibility for saving, particularly in the case of drill and boring jigs provided with guide bushings in the same plane, is met with in the fact that such jigs are adapted to be used in multiple-spindle drills, thereby still more increasing the rapidity with which the work may be produced. In shops where a great many duplicate parts are made, containing a number of drilled holes, multiple-spindle drills of complicated design, which may be rather expensive as regards first cost, are really cheaper, by far, than ordinary simple drill presses.

Another advantage which has been gained by the use of jigs and fixtures, and which should not be lost sight of in the enumeration of the points in favor of building machinery by the use of special tools, is that the details of a machine that has been provided with a complete equipment of accurate and durable jigs and fixtures can all be finished simultaneously in different departments of a large factory, without inconvenience, thus making it possible to assemble the machine at once after receiving the parts from the different departments; and there is no need of waiting for the completion of one part into which another is required to fit, before making this latter part. This gain in time means a great deal in manufacturing, and was entirely impossible under the old-time system of machine building, when each part had to be made in the order in which it went onto the finished machine, and each consecutive part had to be lined up with each one of the previously made and assembled details. Brackets, bearings, etc., had to be drilled in place, often with ratchet drills, which is a slow and always inconvenient operation.

Difference between Jigs and Fixtures. — To exactly define the word "jig," as considered apart from the word "fixture," is difficult, as the difference between a jig and a fixture is oftentimes not very easy to decide. The word jig is frequently, although incorrectly, applied to any kind of a work-holding appliance used in the building of machinery, the same as, in some shops, the word fixture is applied to all kinds of special tools. As a general rule, however, a jig is a special tool, which, while it holds the work, or is held onto the work, also contains guides for the respective tools to be used; whereas a fixture is only holding the work while the cutting tools are performing the operation on the piece, without containing any special arrangements for guiding these tools. The fixture, therefore, must, itself, be securely held or fixed to the machine on which the operation is performed; hence the name. A fixture, however, may sometimes be provided with a number of gages and stops, although it does not contain any special devices for the guiding of the tools.

The definition given, in a general way, would therefore classify jigs as special tools used particularly in drilling and boring operations, while fixtures, in particular, would be those special tools used on milling machines, and, in some cases, on planers, shapers, and slotting machines. Special tools used on the lathe may be either of the nature of jigs or fixtures, and sometimes the special tool is actually a combination of both, in which case the term drilling fixture, boring fixture, etc., is suitable.

Fundamental Principles of Jig Design. — Before entering upon a discussion of the minor details of the design of jigs and fixtures, the fundamental principles of jig and fixture design will be briefly outlined. Whenever a jig is made for a component part of a machine, it is almost always required that a corresponding jig be made up for the place on the machine, or other part, where the first-mentioned detail is to be attached. It is, of course, absolutely necessary that these two jigs be perfectly alike as to the location of guides and gage points. In order to have the holes and guides in the two jigs in alignment, it is advisable, and almost always cheaper and quicker, to transfer the holes or the gage points from the first jig made to the other. In many instances, it is possible to use the same jig for both parts. Cases where the one or the other of these principles is applicable will be shown in the following chapters in the detailed descriptions of drill and boring jigs.

There are some cases where it is not advisable to make two jigs, one for each of the two parts which are to fit together. It may be impossible to properly locate the jig on one of the parts to be drilled, or, if the jig were made, it may be so complicated that it would not be economical. Under such conditions the component part itself may be used as a jig, and the respective holes in this part used as guides for the tools when machining the machine details into which it fits. Guide bushings for the drills and boring bars may then be placed in the holes in the component part itself. In many cases, drilling and boring operations are also done, to great advantage, by using the brackets and bearings already assembled and fastened onto the machine body as guides.

One of the most important questions to be decided before making a jig is the amount of money which can be expended on a special tool for the operation required. In many cases, it is possible to get a highly efficient tool by making it more complicated and more expensive, whereas a less efficient tool may be produced at very small expense. To decide which of these two types of jigs and fixtures should be designed in each individual case depends entirely upon the circumstances. There should be a careful comparison of the present cost of carrying out a certain operation, the expected cost of carrying out the same operation with an efficient tool, and the cost of building that tool itself. Unless this is done, it is likely that the shop is burdened with a great number of special tools and fixtures which, while they may be very useful for the production of the parts for which they are intended, actually involve a loss. It is readily seen how uneconomical it would be to make an expensive jig and fixture for a machine or a part of a machine that would only have to be duplicated a few times. In some cases, of course, there may be a gain in using special devices in order to get extremely good and accurate results.

Locating Points. — The most important requirements in the design of jigs are that good facilities be provided for locating the work, and that the piece to be machined may be easily inserted and quickly taken out of the jig, so that no time is wasted in placing the work in position on the machine performing the work. In some cases, a longer time is required for locating and clamping the piece to be worked upon than is required for the actual machine operation itself. In all such cases the machine performing the work is actually idle the greater part of the time, and, added to the loss of the operator's time, is the increased expense for machine cost incurred by such a condition. For this reason, the locating and clamping of the work in place quickly and accurately should be carefully studied by the designer before any attempt is made to design the tool. In choosing the locating surface or points of the piece or part, consideration must be given to the facilities for locating the corresponding part of the machine in a similar manner. It is highly important that this be done, as otherwise, although the jigs may be alike, as far as their guiding appliances are concerned, there may be no facility for locating the corresponding part in the same manner as the one already drilled, and while the holes drilled may coincide, other surfaces, also required to coincide, may be considerably out of line. One of the main principles of location, therefore, is that two component parts of the machine should be located from corresponding points and surfaces.

If possible, special arrangements should be made in the design of the jig so that it is impossible to insert the piece in any but the correct way. Mistakes are often made on this account in shops where a great deal of cheap help is used, pieces being placed in jigs upside down, or in some way other than the correct one, and work that has been previously machined at the expenditure of a great deal of time is entirely spoiled. Therefore, whenever possible, a jig should be made "fool-proof."

When the work to be machined varies in shape and size, as, for instance, in the case of rough castings, it is necessary to have at least some of the locating points adjustable and placed so that they can be easily reached for adjustment, but, at the same time, so fastened that they are, to a certain extent, positive. In the following chapters different kinds of adjustable locating points will be described in detail.

Clamping Devices. — The strapping or clamping arrangements should be as simple as possible, without sacrificing effectiveness, and the strength of the clamps should be such as to not only hold the piece firmly in place, but also to take the strain of the cutting tools without springing or "giving." When designing the jig, the direction in which the strain of the tool or cutters acts upon the work should always be considered, and the clamps so placed that they will have the highest degree of strength to resist the pressure of the cut.

The main principles in the application of clamps to a jig or fixture are that they should be convenient for the operator, quickly operated, and, when detached from the work, still connected with the jig or fixture itself, so as to prevent the operator from losing them. Many a time, looking for lost straps, clamps, screws, etc., causes more delay in shops than the extra cost incurred in designing a jig or fixture somewhat more complicated, in order to make the binding arrangement an integral part of the fixture itself. Great complication in the clamping arrangements, however, is not advisable. Usually clamping arrangements of this kind work well when the fixture is new, but, as the various parts become worn, complicated arrangements are more likely to get out of order, and the extra cost incurred in repairing often outweighs the temporary gain in quickness of operation.

The judgment of the designer is, in every case, the most important point in the design of jigs and fixtures. Definite rules for all cases cannot be given. General principles can be studied, but the efficiency of the individual tool will depend entirely upon the judgment of the tool designer in applying the general principles of tool design to the case in hand.

When designing the jig or fixture, the locating and bearing points for the work and the location of the clamps must also be so selected that there is as little liability as possible of springing the piece or jig, or both, out of shape, when applying the clamps. The springing of either the one or the other part will cause incorrect results, as the work surfaces will be out of alignment with the holes drilled or the faces milled. The clamps or straps should therefore, as far as possible, be so placed that they are exactly opposite some bearing point or surface on the work.

Weight of Jigs. — The designer must use his judgment in regard to the amount of metal put into the jig or fixture. It is desirable to make these tools as light as possible, in order that they may be easily handled, be of smaller size, and cost less in regard to the amount of material used for their making, but, at the same time, it is poor economy to sacrifice any of the rigidity and stiffness of the tool, as this is one of the main considerations in obtaining efficient results. On large-sized jigs and fixtures, it is possible to core out the metal in a number of places, without decreasing, in the least, the strength of the jig itself. The corners of jigs and fixtures should always be well rounded, and all burrs and sharp edges filed off, so as to make them convenient and pleasant for handling. Smaller jigs should also be made with handles in proper places, so that they may be held in position while working, as in the case of drilling jigs, and also for convenience in moving the jig about.

Jigs Provided with Feet. — Ordinary drill jigs should always be provided with feet or legs on all sides which are opposite the holes for the bushings, so that the jig can be placed level on the table of the machine. These feet also greatly facilitate the making of the jig, making it easier to lay out and plane the different finished surfaces. On the sides of the jig where no feet are required, if the body is made from a casting, it is of advantage to have small projecting lugs for bearing surfaces when laying out and planing. While jigs are most commonly provided with four feet on each side, in some cases it is sufficient to provide the tool with only three feet, but care should be taken in either case that all bushings and places where pressure will be applied to the tool are placed *inside* of the geometrical figure obtained by connecting, by lines, the points of location for the feet.

While it may seem that three feet are preferable to use, because the jig will then always obtain a bearing on all the three feet, which it would not with four feet, if the table of the machine were not absolutely plane, it is not quite safe to use the smaller number of supports, because a chip or some other object is liable to come under one foot and throw the jig and the piece out of line, without this being noticed by the operator. If the same thing happens to a jig with four feet, it will rock and invariably cause the operator to notice the defect. If the table is out of true, this defect, too, will be noticed for the same reason.

Jig feet are generally cast solid with the jig frame. When the jig frame is made from machine steel, and sometimes in the case of cast-iron jigs, detachable feet are used.

Materials for Jigs. — Opinions differ as to the relative merits of cast iron and steel as materials from which to construct the jig and fixture bodies. The decision on this point should depend to a great extent upon the usage to which the fixture is to be put and the character of the work which it is to handle. For small and medium sized work, such as typewriter, sewing machine, gun, adding machine, cash register, phonograph, and similar parts, the steel jig offers decided advantages, but for larger work, such as that encountered in automobile, engine, and machine tool fixtures, the cast-iron jig is undoubtedly the cheaper and more advisable to use. The steel jig should be left soft in order that at any future time additional holes may be added, or the existing bushings changed as required. With a cast-iron jig this adding of bushings is a difficult matter, as the frame is usually bossed and "spot finished" at the point where the bushings are located, and it is very difficult to build up on the jig frame in order to locate or change the bushings. When designing the jig, these points should be remembered and provision made for them, where possible.

General Remarks on Jig Design. — One mistake, quite frequently made, is that of giving too little clearance between the piece to be machined and the walls or sides of the jig used for it. Plenty of clearance should always be allowed, particularly when rough castings are being drilled or machined in the jigs; besides, those surfaces in the jig which do not actually bear upon the work do not always come exactly to the dimensions indicated on the drawing, particularly in a cast-iron jig, and allowance ought to be made for such differences.

In regard to the locating points, it ought to be remarked that, in all instances, these should be visible to the operator when placing the work in position, so that he may be enabled to see that the work really is in its right place. At times the construction of the piece to be worked upon may prevent a full view of the locating points. In such a case a cored or drilled hole in the jig, near the locating seat, will enable a view of same, so that the operator may either see that the work rests upon the locating point, or so that he can place a feeler or thickness gage between the work and the locating surface, to make sure that he has the work in its correct position. Another point that should not be overlooked is that jigs and fixtures should be designed with a view of making them easily cleaned from the chips, and provision should also be made so that the chips, as far as possible, may fall out of the jig and not accumulate on or about the locating points, where they are liable to throw the work out of its correct position and consequently spoil the piece.

The principles so far referred to have all been in relation to the holding of the work in the jig, and the general design of the jig for producing accurate work. Provisions, however, should also be made for clamping the jig or fixture to the table of the machine, in cases where it is necessary to have the tool fixed while in operation. Small drilling jigs are not clamped to the table, but boring jigs and milling and planing fixtures invariably must be firmly secured to the machine on which they are used.

Plain lugs, projecting out in the same plane as the bottom of the jig, or lugs with a slot in them to fit the body of T-bolts, are the common means for clamping fixtures to the table. For boring jigs, it is unnecessary to provide more than three such clamping points, as a greater number is likely to cause some springing action in the fixture. A slight springing effect is almost unavoidable, no matter how strong and heavy the jig is, but, by properly applying the clamps, it is possible to confine this springing within commercial limits.

Jigs should always be tested before they are used, so as to make sure that the guiding provisions are placed in the right relation to the locating points and in proper relation to each other.

Summary of Principles of Jig Design. — Summarizing the principles referred to, the following rules may be given as the main points to be considered in the designing of jigs and fixtures:

1. Before planning the design of a tool, compare the cost of production of the work with present tools with the expected cost of production, using the tool to be made, and see that the cost of building is not in excess of expected gain.

2. Before laying out the jig or fixture, decide upon the locating points and outline a clamping arrangement.

3. Make all clamping and binding devices as quick-acting as possible.

4. In selecting locating points, see that two component parts of a machine can be located from corresponding points and surfaces.

5. Make the jig "fool-proof"; that is, arrange it so that the work cannot be inserted except in the correct way.

6. For rough castings, make some of the locating points adjustable.

7. Locate clamps so that they will be in the best position to resist the pressure of the cutting tool when at work.

8. Make, if possible, all clamps integral parts of the jig or fixture.

9. Avoid complicated clamping arrangements, which are liable to wear or get out of order.

10. Place all clamps as nearly as possible opposite some bearing point of the work, to avoid springing.

11. Core out all unnecessary metal, making the tools as light as possible, consistent with rigidity and stiffness.

12. Round all corners.

13. Provide handles wherever these will make the handling of the jig more convenient.

14. Provide feet, preferably four, opposite all surfaces containing guide bushings in drilling and boring jigs.

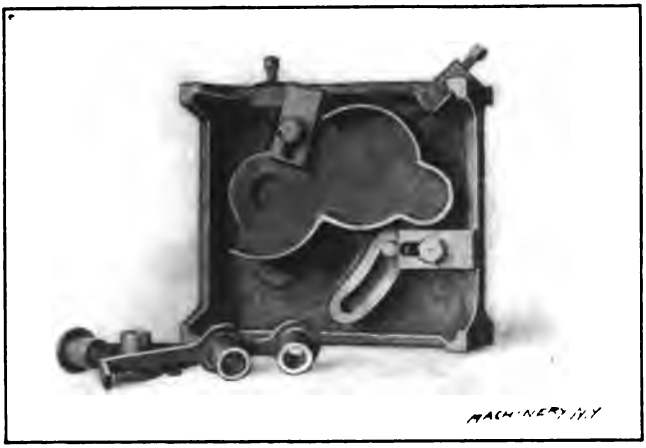


Fig. 1. Typical Open Drill Jig for Gear Guard

15. Place all bushings inside of the geometrical figure formed by connecting the points of location of the feet.

16. Provide abundant clearance, particularly for rough castings.

17. Make, if possible, all locating points visible to the operator when placing the work in position.

18. Provide holes or escapes for the chips.

19. Provide clamping lugs, located so as to prevent springing of the fixture, on all tools which must be held to the table of the machine while in use, and tongues for the slots in the tables in all milling and planing fixtures.

20. Before using in the shop, for commercial purposes, test all jigs as soon as made.

Types of Jigs. — The two principal classes of jigs are drill jigs and boring jigs. Fixtures may be grouped as milling, planing, and splining fixtures, although there are a number of special fixtures which could not be classified under any special head.

Drill jigs are intended exclusively for drilling, reaming, tapping, and facing. Whenever these four operations are required on a piece of work, it is, as a rule, possible to provide the necessary arrangements for performing all these operations in one and the same jig. Sometimes separate jigs are made for each one of these operations, but it is doubtless more convenient and cheaper to have one jig do for all, as the design of the jig will not be much more complicated. Although it may be possible to make a distinction between a number of different types of drill jigs, it is almost impossible to define and to get proper names for the various classes, owing to the great variety of shapes of the work to be drilled. There are, however, two general types that are most commonly used, the difference between them being very marked. These types may be classified as *open jigs* and *closed jigs*, or *box jigs*. Sometimes the open jigs are called *clamping jigs*. The open jigs usually have all the drill bushings in the same plane, parallel with one another, and are not provided with loose or removable walls or leaves, thereby making it possible to insert

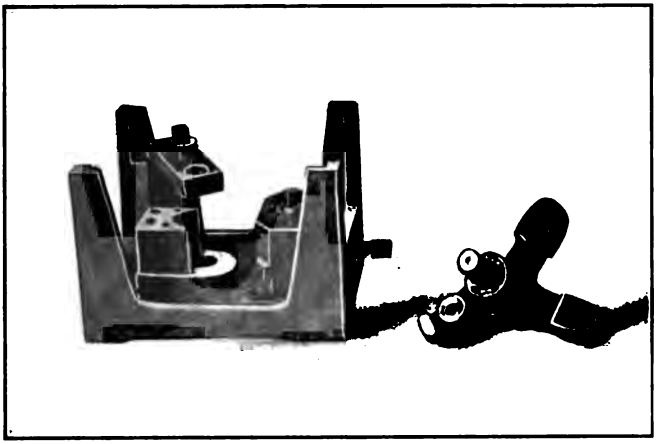


Fig. 2. Open Drill Jig, showing Commonly Used Design

the piece to be drilled without any manipulation of the parts of the jig. These jigs are often of such a construction that they are applied to the work to be drilled, the jig being placed on the work, rather than the work being placed in the jig. The work is held to the jig (or the jig to the work) by straps, hook-bolts, or clamps. Figs. 1 and 2 show types of open drill jigs.

The closed drill jigs, or box jigs, frequently resemble some form of a box and are intended for pieces where the holes are to be drilled at various angles to one another. As a rule, the walls are solid with the face of the jig, and the piece to be drilled can be inserted only after one or more leaves or covers have been swung out of the way. Sometimes it is necessary to remove a loose wall, which is held by screws and dowel pins, in order to locate the piece in the jig. The work in the closed drill jig is generally held in place by set-screws and sometimes by screw bushings, as well as by straps and hook-bolts. Fig. 3 shows an example of a typical closed jig.

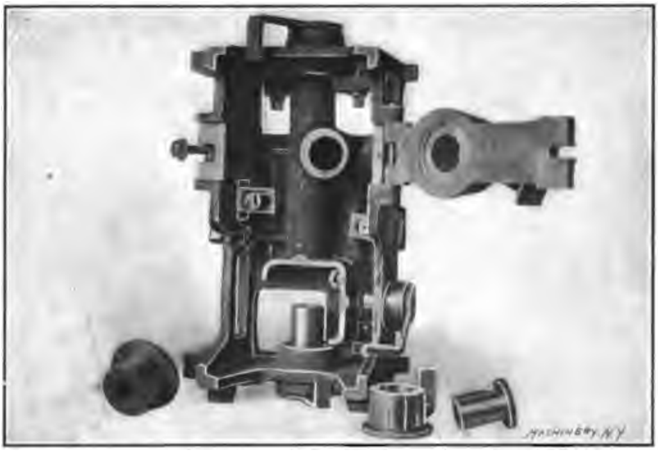


Fig. 3. Closed Drill Jig, showing Leaf opened

Another type of closed jig is exemplified in a combination of drill and boring jigs, designed to serve both for drilling and boring operations. Before designing a combination drill and boring jig, the relation between, and number of, the drilled and bored holes must be taken into consideration, and also the size of the piece to be machined. In case there is a great number of holes, it may be of advantage to have two or even more jigs for the same piece, because it makes it easier to design and make the jig, and very likely will give a better result. The holes drilled or bored in the first jig may be used as a means for locating the piece in the jigs used later on. Combination drill and boring jigs are not very well adapted for pieces of large size. In Fig. 4 is shown a typical combination jig, where the bushings for guiding the drills are located in the bottom surface, the work upon which the operations are performed being shown at the left-hand side in the illustration.

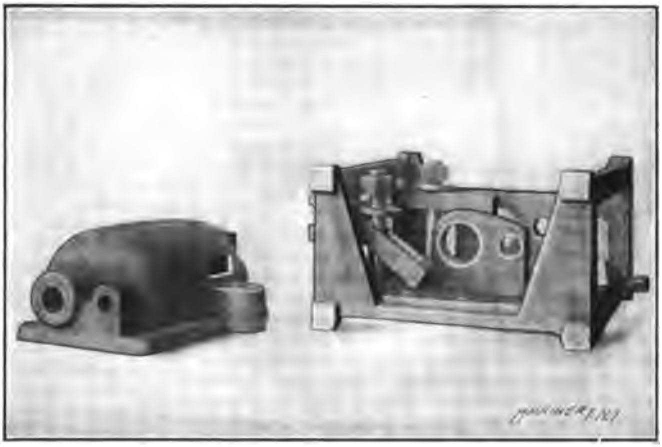


Fig. 4. Combination Drill and Boring Jig

Open Jigs. — As the use of drill jigs makes it possible to perform drilling operations quickly as well as accurately, jigs are used very extensively in all modern shops. Those shown in Figs. 8 and 11, Chapter I, represent a very simple type that is often used for drilling flanges, plates, or similar parts. Jigs of this class, as well as those of other types, are made in a great variety of shapes, and, when in use, they are either applied to the work or the latter is placed in the jig. When the work is quite large, the jig is frequently placed on it, whereas small parts are more often held in the jig, which is so designed that the work can be clamped in the proper position. The form of any jig depends, to a great extent, on the shape of the work for which it is intended and also on the location of the holes to be drilled. As the number of differently shaped pieces which go to make up even a single machine is often very great, and as most parts require more or less drilling, jigs are made in an almost endless variety of sizes and forms. When all the holes to be drilled in a certain part are parallel, and especially if they are all in the same plane, a very simple form of jig can ordinarily be used; in fact, jigs for work of this class are often little more than flat plates having the necessary guide bushings and, perhaps, one or two clamps for holding the jig and work together.

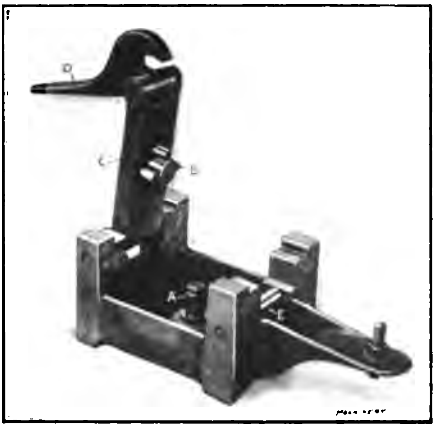


Fig. 5. Drill Jig of the Box Type

Box Jigs. — A great many parts, however, must be drilled on different sides and, frequently, the work is very irregular in shape, so that a jig which is made somewhat in the form of a box, and encloses the work, is very essential, as it enables the guide bushings to be placed on all sides and also makes it comparatively easy to locate and securely clamp the part in the proper position for drilling. This type of jig, which, because of its form, is known as a closed or "box jig," is used very extensively.

A box jig of simple design is shown in Fig. 5. This particular jig is used for drilling four small holes in a part (not shown) which is located with reference to the guide bushings *B* by a central pin *A* attached to the jig body. This pin enters a hole in the work, which is finished in another machine in connection with a previous operation. After the work is inserted in the jig, it is clamped by closing the cover *C*, which is hinged at one end and has a cam-shaped clamping latch *D* at the other, that engages a pin *E* in the jig body. The four holes are drilled by passing the drill through the guide bushings *B* in the cover.

Another jig of the same kind, but designed for drilling a hole having two diameters through the center of a steel ball, is shown in Fig. 6. The work, which is shown enlarged at *A*, is inserted while the cover is thrown back as indicated by the dotted lines. The cover is then closed and tightened by the cam-latch *D*, and the large part of the hole is drilled with the jig in the position shown. The jig is then turned over and a smaller drill of the correct size is fed through guide bushing *B* on the opposite side. The depth of the large hole could be gaged for each ball drilled, by feeding the drill spindle down to a certain position as shown by graduation or other marks, but if the spindle has an adjustable stop, this should be used. The work is located in line with the two guide bushings by spherical seats formed in the jig body and in the upper bushing, as shown. As the work can be inserted and removed quickly, a large number of balls, which, practically speaking, are duplicates, can be drilled in a comparatively short time by using a jig of this type.

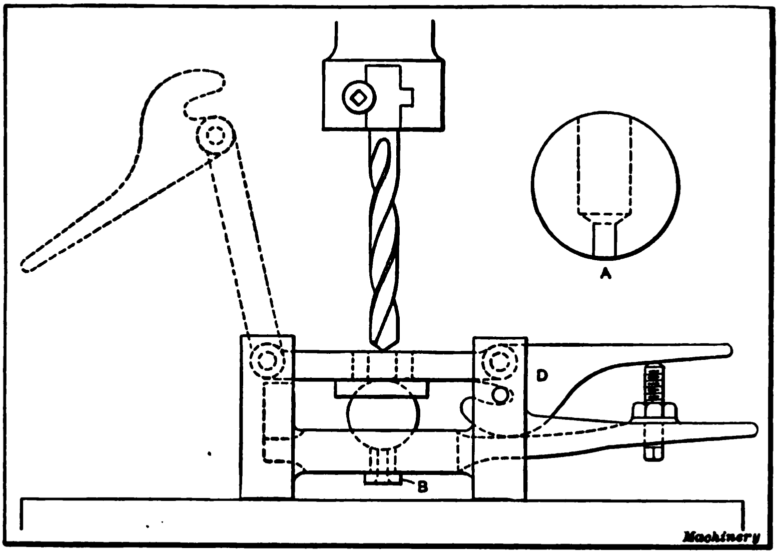


Fig. 6. Box Jig for Drilling Ball shown enlarged at A

A box jig that differs somewhat in construction from the design just referred to is illustrated at *A* in Fig. 7, which shows a side and top view. The work, in this case, is a small casting the form of which is indicated by the heavy dot-and-dash lines. This casting is drilled at *a*, *b*, and *c*, and the two larger holes *a* and *b* are finished by reaming. The hinged cover of this jig is opened for inserting the work by unscrewing the T-shaped clamping screw *s* one-quarter of a turn, which brings the head in line with a slot in the cover. The casting is clamped by tightening this screw, which forces an adjustable screw bushing *g* down against the work. By having this bushing adjustable, it can be set to give the right pressure, and, if the height of the castings should vary, the position of the clamping bushing could easily be changed.

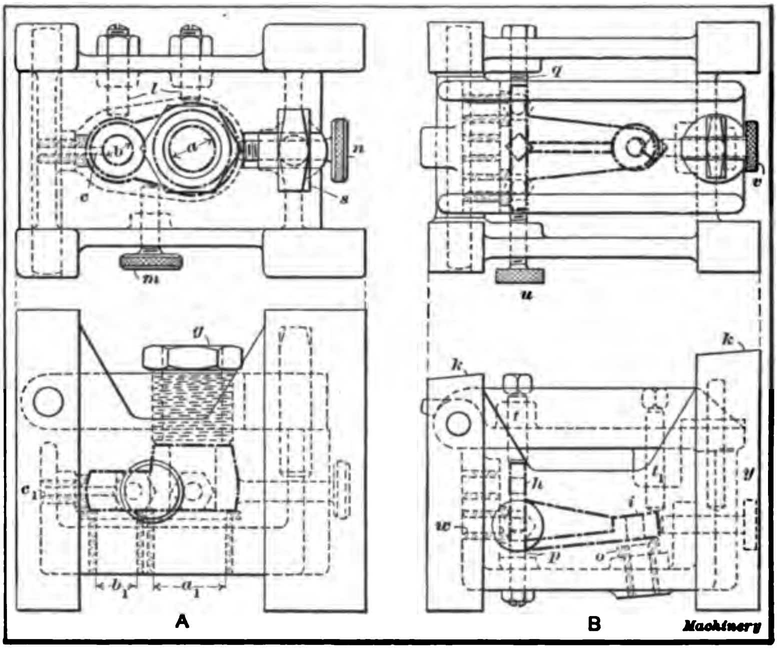


Fig. 7. Box Jigs for Drilling Parts shown by Heavy Dot-and-dash Lines

The work is properly located by the inner ends of the three guide bushings a_1, b_1, and c_1, and also by the locating screws *l* against which the casting is held by knurled thumb-screws *m* and *n*. When the holes *a* and *b* are being drilled, the jig is placed with the cover side down, as shown at *A* in Fig. 8, and the drill is guided by removable bushings, one of which is shown at *r*. When the drilling is completed, the drill bushings are replaced by reamer bushings and each hole is finished by reaming. The small hole *c* is drilled in the end of the casting by simply placing the jig on end as shown at *B*. Box jigs which have to be placed in more than one position for drilling the different holes are usually provided with feet or extensions, as shown, which are accurately finished to properly align the guide bushings with the drill. These feet extend beyond any clamping screws, bolts, or bushings which may protrude from the sides of the jigs, and provide a solid support. When inserting work in a jig, care should be taken to remove all chips which might have fallen onto those surfaces against which the work is clamped and which determine its location.

Still another jig of the box type, which is quite similar to the one shown at *A*, Fig. 7, but is arranged differently, owing to the shape of the work and location of the holes, is shown at *B* in the same illustration. The work has three holes in the base *h*, and a hole at *i* which is at an angle of 5 degrees with the base. The three holes are drilled with the jig standing on the opposite end *y*, and the angular hole is drilled while the jig rests on the four feet *k*, the ends of which are at such an angle with the jig body that the guide bushing for hole *i* is properly aligned with the drill. The casting is located in this jig by the inner ends of the two guide bushings *w* and the bushing *o* and also by two locating screws *p* and a side locating screw *q*. Adjustable screws t and t_1 in the cover hold the casting down, and it is held laterally by the two knurled thumb-screws *u* and *v*. If an attempt were made to drill this particular part without a jig (as would be done if only a few castings were needed) it would have to be set with considerable care, provided the angle between hole *i* and those in the base had to be at all accurate, and it would be rather difficult to drill a number of these castings and have them all duplicates. By the use of a jig, however, designed for drilling this particular casting, the relative positions of the holes in any number of parts are practically the same and the work can be done much more quickly than would be possible if it were held to the drill-press table by ordinary clamping appliances. These jig designs have been referred to somewhat in detail to show, in a general way, how jigs are constructed and used.

Details of Jig Design. — The general principles of the design and use of jigs have been explained. The details of jig design will now be considered. Generally speaking, the most important parts of a jig are the guide bushings for the drills and other tools; the clamping devices; and the locating points, against which the work is placed to insure accurate position in the jig.

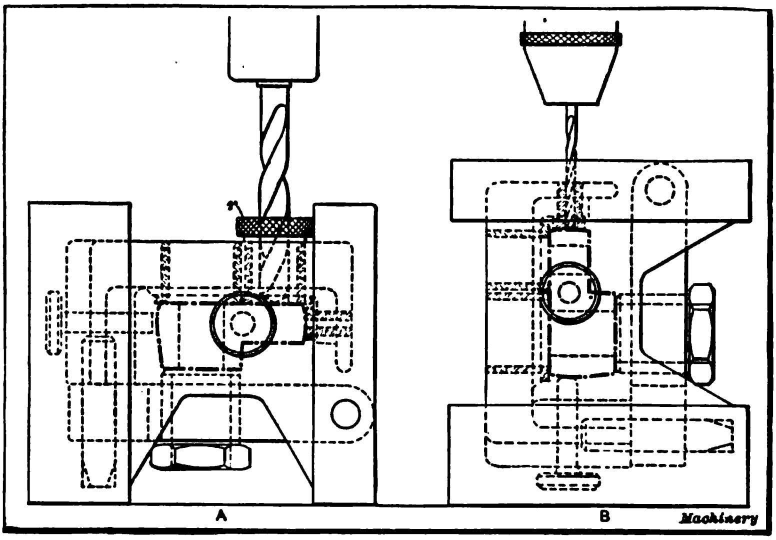


Fig. 8. Method of Using Jig

The guides for the cutting tools in a drill jig take the form of concentric steel bushings, which are hardened and ground and placed in the jig body in proper positions. The bushings may be either stationary or removable, which latter, in the shop, are usually termed "loose bushings."

The drill bushings are generally made of tool steel, hardened and lapped, and, where convenient, should be ground inside and out. They should also be long enough to support the drill on each side regardless of the fluting, and they should be so located that the lower end of the bushings will stop about the same distance above the work as the diameter of the drill, so that chips will clear the bushings readily. Where holes are drilled on the side of a convex or a concave surface, the end of the bushing must be cut on a bevel and come closer to the part being drilled, to insure the drill having adequate support while starting into the work. The bushings should have heads of sufficient diameter. Long bushings should be relieved by increasing the hole diameter at the upper end. The lower end of the bushing should have its edges rounded, in order to permit some of the chips being shed from the drill easily, instead of all of them being forced up through the bushing. It is also good practice to cut a groove under the head for clearance for the wheel when grinding the bushing on the outside. A complete treatise covering dimensions and design is given in the chapter on "Jig Bushings."

In order to hold the work rigidly in the jig, so that it may be held against the locating points while the cutting tools operate upon the work, jigs and fixtures are provided with clamping devices. Sometimes a clamping device serves the purpose of holding the jig to the work, in a case where the work is a very large piece and the jig is attached to the work in some suitable way. The purpose of the clamping device, however, remains the same, namely, that of preventing any shifting of the guiding bushings while the operation on the work is performed. The clamping device should always be an integral part of the jig body in order to prevent its getting lost. Different types of clamping devices are shown and described in the chapter on "Jig Clamping Devices."

The locating points may consist of screws, pins, finished pads, bosses, ends of bushings, seats, or lugs cast solid with the jig body, etc. The various types used are described in detail in the chapter on "Locating Points and Adjustable Stops."

CHAPTER VIII

JIG BUSHINGS

The drills, counterbores, reamers, etc., used in connection with drill jigs are guided by steel bushings, which are hardened and ground, and placed in the jig body in their proper location. These bushings may be of two kinds: stationary and removable, the latter usually being known as "loose" bushings. The most common and the preferable form for the stationary bushing is shown in Fig. 1. This bushing is straight both on the inside and on the outside, except that the upper corners *A* on the inside are given a liberal radius, so as to allow the drill to enter the hole easily, while the corners *B* at the lower end of the outside are slightly rounded for the purpose of making it easier to drive the bushing into the hole, when making the jig, and also to prevent the sharp corner on the bushing from cutting the metal in the hole into which the bushing is driven.

Removable Bushings. — When removable bushings are used, they should never be placed directly in the jig body, except if the jig be used only a few times, but the hole should always be provided with a lining bushing. This lining bushing is always made of the form shown in Fig. 1. If the hole bored in the jig body receives the loose or removable bushing directly, the inserting and removing of the bushing, if the jig is frequently used, would soon wear the walls of the hole in the jig body, and after a while the jig would have to be replaced, or at least the hole would have to be bored out, and a new removable bushing made to fit the larger-sized hole. In order to overcome this, the hole in the jig body is bored out large enough to receive the lining bushing referred to, which is driven in place. This lining bushing then, in turn, receives the loose bushing, the outside diameter of which closely fits the inside diameter of the lining bushing, as shown in Fig. 2, in which *A* is the jig body, *B* the lining bushing, and *C* the loose bushing. Both of these bushings are hardened and ground so that they will stand constant use and wear for some length of time. When no removable bushings are required, the lining bushing itself becomes the drill bushing or reamer bushing, and the inside diameter of the lining bushing will then fit the cutting tool used. The bushing shown in Fig. 1 is cheaper to make, and will work fully as well, when driven in place in the hole receiving it, as do bushings having a shoulder at the upper end, such as the loose bushing shown in Fig. 2. It was the practice some years ago to make all bushings with a shoulder, but this is unnecessary, and simply increases the cost of making the bushing.

Material for Jig Bushings. — Bushings are generally made of a good grade of tool steel to insure hardening at a fairly low temperature and to lessen the danger of fire cracking. They can also be made from machine steel, which will answer all practical purposes, provided the bushings are properly case-hardened to a depth of about $\frac{1}{16}$ inch. Sometimes bushings for guiding tools may be made of cast iron, but only when the cutting tool is of such a design that no cutting edges come within the bushing itself. For example, bushings used simply to support the smooth surface of a boring-bar or the shank of a reamer might, in some instances, be made of cast iron, but hardened steel bushings should always be used for guiding drills, reamers, taps, etc., when the cutting edges come in direct contact with the guiding surfaces. If the outside diameter of the bushing is very large, as compared with the diameter of the cutting tool, the cost of the bushing can sometimes be reduced by using an outer cast-iron body and inserting a hardened tool steel bush-

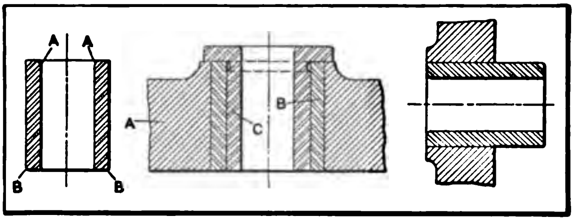


Fig. 1. Fig. 2. Fig. 3.

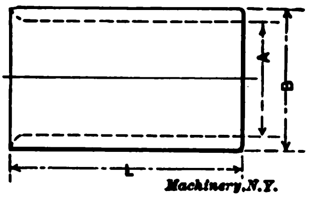
ing. Occasionally a bushing having a large outside diameter is required as, for example, when a large counterbore must be used in a small hole, which makes it necessary to have a large opening in the jig body.

Dimensions of Stationary Jig Bushings. — Standard dimensions for jig bushings, applicable under all circumstances, cannot be given, as these depend, in most cases, on the different conditions of the various classes of jigs in which the bushings are inserted. The common practice is to make the length of the bushing twice the inside diameter of the hole in the bushing for stationary drill bushings. On very small bushings, however, say $\frac{1}{4}$ inch diameter hole and less, the length of the bushing will have to be made longer than twice the diameter, while on very large bushings the length may be made somewhat less than twice the diameter. Table I gives proportions of stationary drill bushings. The dimensions, as here given, will be found suitable in all cases where no special conditions demand deviation from ordinary practice. If the jig wall is thin, the bushing may project out as shown in Fig. 3, so as to give the cutting tool the proper guiding and support as close to the work as possible. In Table II are given dimensions for lining bushings, not intended to directly guide the drill, but to hold removable bushings, which, in turn, guide the cutting tools. The dimensions given in Tables I and II are for bushings made from either tool steel or machine steel.

While it is difficult, in some cases, to draw a distinct line between stationary drill bushings and lining bushings, it may be said, in general, that the bushings in Table I are used for guiding the drills when drilling holes directly, either with a full-sized drill, when the hole is not required to be very smooth or accurate, or, if greater accuracy is required, for guiding a spotting drill which fits the bushings exactly, after which the hole is drilled out with a so-called "reamer-drill," which is 0.010 inch or less under the size of the finished hole, and finally reamed out with a reamer exactly fitting the hole in the bushing. These bushings are thus, in general, used when no tapping or counterboring would be required. The lining bushing in Table II, again, may guide one of the tools for the holes to be finished directly, and then removable bushings are inserted to guide the other tools used.

Miscellaneous Types of Drill Bushings. — As mentioned, it was, some years ago, general practice to provide even stationary bushings with a shoulder or head, as shown in bushing *C*, Fig. 2. This will prevent the bushing from being pushed through the jig by the cutting tool, but this seldom happens if the bushings are made to fit the tool correctly. Sometimes the shoulder is used to take the thrust of a stop-collar, which is clamped on the drill, to allow it to go down to a certain depth, as shown in Fig. 4, in which *C* is the stop-collar, *D* the wall of the jig, and *E* the stationary bushing; *F* is the work. In such a case, a shoulder on the bushing should be provided.

Table I. Dimensions of Stationary Drill Bushings

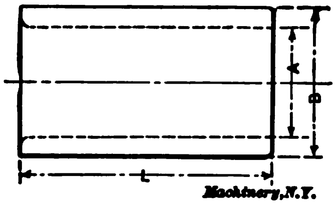


A	*B*	*L*	*A*	*B*	*L*	*A*	*B*	*L*	*A*	*B*	*L*
1/16	3/16	3/8	9/16	13/16	1 1/8	1 1/16	1 7/16	2	1 9/16	1 15/16	2 3/4
1/8	1/4	1/2	5/8	7/8	1 1/4	1 1/8	1 1/2	2 1/8	1 5/8	2	2 7/8
3/16	5/16	1/2	11/16	15/16	1 3/8	1 3/16	1 9/16	2 1/8	1 11/16	2 1/8	2 7/8
1/4	3/8	5/8	3/4	1	1 1/2	1 1/4	1 5/8	2 1/4	1 3/4	2 1/4	3
5/16	1/2	5/8	13/16	1 1/8	1 1/2	1 5/16	1 11/16	2 1/4	1 13/16	2 5/16	3 1/8
3/8	9/16	3/4	7/8	1 3/16	1 5/8	1 3/8	1 3/4	2 3/8	1 7/8	2 3/8	3 1/4
7/16	5/8	7/8	15/16	1 1/4	1 3/4	1 7/16	1 13/16	2 1/2	1 15/16	2 7/16	3 3/8
1/2	11/16	1	1	1 3/8	1 7/8	1 1/2	1 7/8	2 5/8	2	2 5/8	3 1/2

If the work to be drilled is located against a finished seat or boss on the wall of the jig, and the wall is not thick enough to take a bushing of standard length, then it is common practice to make a bushing having a long head, as shown in Fig. 5. The length *A* of the head can be extended as far as necessary to get the proper bearing. As the bushing is driven in place and the shoulder of the head bears against the finished surface of a boss on the jig, it will give the cutting tool almost as rigid a bearing as if the jig metal surrounded the bushing all the way up.

Removable bushings are frequently used for work which must be drilled, reamed, and tapped, there then being one bushing for each of the cutting tools. They are also used when different parts of the same hole are to be drilled out to different diameters, or when the upper portion of the hole is counterbored, or when a lug has to be faced off. In this case, each tool, of course, has its own guide bushing. The common design of removable bushings is shown in Fig. 6. The outside is made to fit the inside of the lining bushing with a nice sliding fit, so that it can be gently pressed into the lining bushing by the hand. The distance *A* under the head of the bushing should be the same length as, or longer than, the guide bushing. The thickness *B* of the head varies, of course, according to the size of the bushing. The diameter *C* of the head should be

Table II. Dimensions of Lining Bushings



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A	*B*	*L*	*A*	*B*	*L*	*A*	*B*	*L*
5/16	1/2	1/2	1 1/8	1 1/2	1 1/2	2 1/8	2 5/8	2 5/8
3/8	9/16	1/2	1 1/4	1 5/8	1 5/8	2 3/16	2 11/16	2 3/4
7/16	5/8	5/8	1 5/16	1 11/16	1 3/4	2 1/4	2 3/4	2 7/8
9/16	13/16	5/8	1 3/8	1 3/4	1 7/8	2 5/16	2 7/8	2 7/8
5/8	7/8	3/4	1 7/16	1 13/16	2	2 3/8	3	3
11/16	15/16	7/8	1 9/16	1 15/16	2 1/8	2 9/16	3 3/16	3 1/8
3/4	1	1	1 5/8	2	2 1/8	2 5/8	3 1/4	3 1/4
13/16	1 1/8	1 1/8	1 3/4	2 1/4	2 1/4	2 11/16	3 5/16	3 3/8
15/16	1 1/4	1 1/4	1 13/16	2 5/16	2 1/4	2 3/4	3 3/8	3 1/2
1	1 3/8	1 3/8	1 7/8	2 3/8	2 3/8	....	....	....
1 1/16	1 7/16	1 1/2	1 15/16	2 7/16	2 1/2	....	....	....

from $\frac{1}{4}$ to $\frac{1}{2}$ inch larger than the diameter *D* of the bushing. A groove *E*, $\frac{1}{8}$ to $\frac{1}{4}$ inch wide, is cut immediately under the head, so that the emery wheel can pass clear over the part being ground.

Means for Preventing Loose Bushings from Turning. — In order to prevent the bushings from turning, in some shops a collar, with a projecting tail, as shown in Fig. 7, is forced over the head of the bushing. This arrangement also makes it easy to remove the bushing. The dog, as it is commonly called, is usually bent at the end of the tail, as shown in the illustration, one end resting against some part of the jig, the proportions of which the dog must suit. Sometimes the bent end is left straight, if there is a possibility for the tail to strike against some lug in the same plane. The making of such dogs involves some extra expense, but it is very effective in avoiding troubles with bushings turning and working their way out of the holes. In some cases simply a hole is drilled in the shoulder of the bushing at the edge, and a corresponding pin is driven into the jig body. This serves the same purpose as the dog. It is probably cheaper,

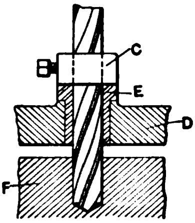


Fig. 4.

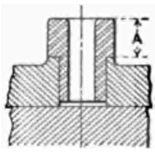


Fig. 5.

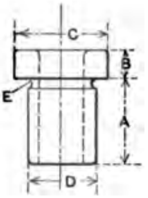


Fig. 6.

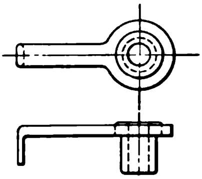


Fig. 7.

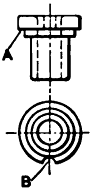


Fig. 8.

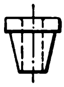


Fig. 9.

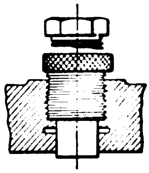


Fig. 10.

but it does not add the convenient means for removing the bushing as does the dog. To make such a bushing more easily removable, the arrangement shown in Fig. 8 is probably the most common. A step *A* is turned down on the head, which, in this case, will have to be a trifle larger in diameter. This step permits some kind of a tool — a screw driver, for instance, to be put underneath, and with a jerk the bushing may be lifted enough to get a good hold on it. The half-round slot at *B* is milled or filed in the periphery of the head, and fits over a pin or screw which is fastened in the jig body, as mentioned before.

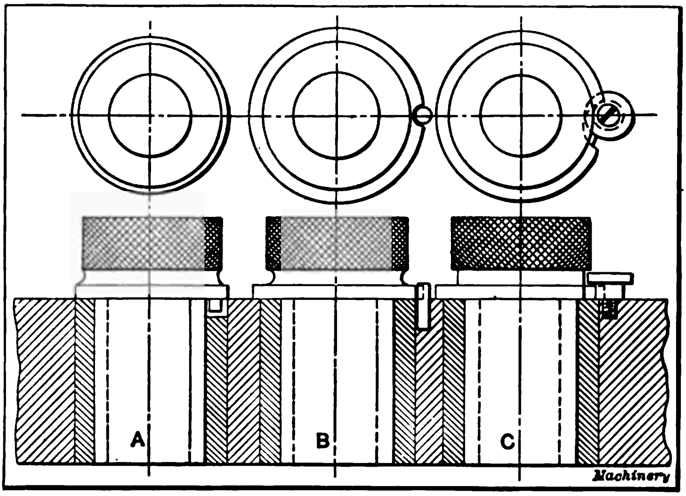


Fig. 11. Methods used for Preventing Jig Bushings from Turning

In Fig. 11 are shown three methods of holding bushings to prevent them from turning, the methods all being on the principle described: *A* shows a bushing having a pin inserted which slips in a slot cut in the lining bushing; *B* shows a bushing having a slot milled through the collar, a pin being located in the jig to engage this slot; and *C* illustrates a more elaborate device that is sometimes used. The stop button which is fastened to the jig prevents the bushing from being drawn out of the liner while withdrawing drills or reamers, as well as preventing it from turning.

The following method for holding slip jig bushings in place has been found to be a very good one: Drill and tap a $\frac{1}{4}$- or $\frac{3}{8}$-inch hole in the side of the jig bushing, as indicated in Fig. 12. After the bushing is hardened and ground, screw in a pin and cut it off so that it projects about $\frac{3}{16}$ inch outside of the bushing, as at *B*. Chip out a slot in each hole in the jig as indicated at *A*, the hole being chipped in the direction of a spiral. By engaging the projecting pin in this slot, the bushing is prevented from turning and from rising out of the hole. At the same time it can easily be removed when required, and there is no projection on the jig of any kind that can be broken off while handling. It is not always necessary to tap a hole for the pin in the jig bushing. A plain drilled hole is sufficient when the bushing is at least $\frac{3}{8}$ inch thick. If the wall of the bushing is thinner than this, the pin cannot be driven in tightly enough to stay in place securely.

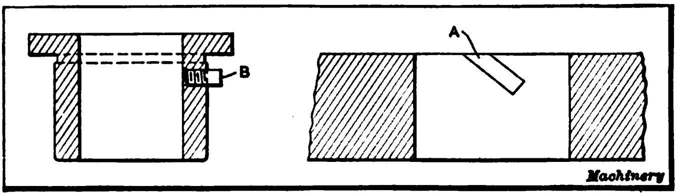
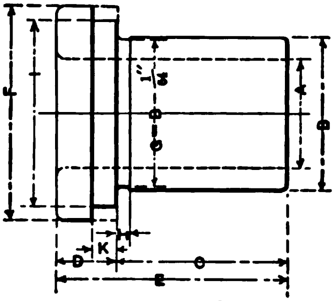


Fig. 12. Another Method for Preventing Drill Bushings from Turning

Dimensions of Removable Bushings. — In Table III are given dimensions for removable bushings of the type shown in Fig. 8. Table IV gives dimensions for bushings for holes which are reamed with a rose chucking reamer, after having first been drilled with a drill $\frac{1}{16}$ inch smaller than the diameter of the reamer with which the hole is finally reamed out. The bushing to the extreme right, over the table, is the lining bushing, which is made of machine steel, casehardened and ground. The bushing to the extreme left is the bushing for the rose chucking reamer. It is made of cast iron and ground. The bushing in the center is the drill bushing which is made from tool steel, hardened and ground, or, in cases where it does not seem warranted to make the bushing of tool steel, of machine steel, casehardened and ground.

The tapered removable bushing shown in Fig. 9 is objection-

Table III. Dimensions of Removable Drill Bushings



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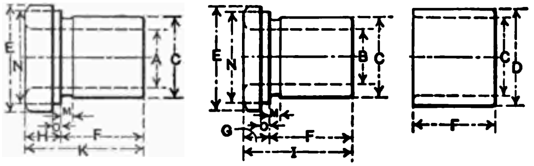
A	*B*	*C*	*D*	*E*	*F*	*H*	*I**	*K**
1/8	5/16	1/2	1/8	5/8	5/8	1/8	1/2	1/32
3/16	3/8	1/2	1/8	5/8	5/8	1/8	1/2	1/32
1/4	7/16	5/8	1/8	3/4	3/4	1/8	5/8	1/32
5/16	9/16	5/8	1/8	3/4	7/8	1/8	3/4	1/32
3/8	5/8	3/4	1/8	7/8	7/8	1/8	3/4	1/32
7/16	11/16	7/8	1/8	1	1	1/8	7/8	1/32
1/2	3/4	1	1/8	1 1/8	1	1/8	7/8	1/32
9/16	13/16	1 1/8	1/8	1 1/4	1 1/8	1/8	1	1/32
5/8	15/16	1 1/4	3/16	1 7/16	1 1/4	1/8	1 1/8	1/16
11/16	1	1 3/8	3/16	1 9/16	1 1/4	1/8	1 1/8	1/16
3/4	1 1/16	1 1/2	3/16	1 11/16	1 3/8	1/8	1 1/4	1/16
13/16	1 1/8	1 1/2	3/16	1 11/16	1 3/8	1/8	1 1/4	1/16
7/8	1 1/4	1 5/8	3/16	1 13/16	1 1/2	1/8	1 3/8	1/16
15/16	1 5/16	1 3/4	3/16	1 15/16	1 5/8	1/8	1 1/2	1/16
1	1 3/8	1 7/8	1/4	2 1/8	1 3/4	3/16	1 5/8	3/32
1 1/16	1 7/16	2	1/4	2 1/4	1 7/8	3/16	1 3/4	3/32
1 1/8	1 9/16	2 1/8	1/4	2 3/8	2	3/16	1 13/16	3/32
1 3/16	1 5/8	2 1/8	1/4	2 3/8	2	3/16	1 13/16	3/32
1 1/4	1 3/4	2 1/4	5/16	2 9/16	2 1/8	3/16	1 15/16	1/8
1 5/16	1 13/16	2 1/4	5/16	2 9/16	2 1/4	3/16	2 1/16	1/8
1 3/8	1 7/8	2 3/8	5/16	2 11/16	2 1/4	3/16	2 1/16	1/8
1 7/16	1 15/16	2 1/2	5/16	2 13/16	2 3/8	3/16	2 3/16	1/8
1 1/2	2 1/8	2 5/8	3/8	3	2 1/2	3/16	2 5/16	1/8
1 9/16	2 3/16	2 3/4	3/8	3 1/8	2 5/8	3/16	2 7/16	1/8
1 5/8	2 1/4	2 7/8	3/8	3 1/4	2 5/8	3/16	2 7/16	1/8
1 11/16	2 5/16	2 7/8	3/8	3 1/4	2 3/4	3/16	2 9/16	1/8
1 3/4	2 3/8	3	3/8	3 3/8	2 3/4	3/16	2 9/16	1/8
1 13/16	2 9/16	3 1/8	1/2	3 5/8	3	1/4	2 13/16	5/32
1 7/8	2 5/8	3 1/4	1/2	3 3/4	3 1/8	1/4	2 15/16	5/32
1 15/16	2 11/16	3 3/8	1/2	3 7/8	3 1/8	1/4	2 15/16	5/32
2	2 3/4	3 1/2	1/2	4	3 1/4	1/4	3 1/16	5/32

* When using dogs as illustrated in Fig. 7, the dimensions in these columns are omitted.

able on account of being expensive to make, and also on account of being likely to be thrown out of true by chips, etc., forced in between the outside of the bushing and the hole.

Screw Bushings. — Sometimes removable bushings are threaded on the outside and made to fit a tapped hole in the jig, as shown in Fig. 10. The lower part of the bushing is usually turned straight, and ground, in order to center the bushing perfectly in the hole in the jig. The head of the bushing is either knurled or milled hexagon for a wrench. When these bushings are used, they are, as a rule, not used for the single purpose of guiding the cutting tool, but they combine with this the purposes of locating and clamping the work. For such

Table IV. Bushings for Holes Reamed with Rose Chucking Reamers



A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*K*	*M*	*N*	*O*
3/4	11/16	1 1/4	1 5/8	1 1/2	1 1/4	3/16	1/4	1 7/16	1 1/2	1/8	1 3/8	1/16
13/16	3/4	1 5/16	1 11/16	1 5/8	1 5/16	3/16	1/4	1 1/2	1 9/16	1/8	1 1/2	1/16
7/8	13/16	1 3/8	1 3/4	1 5/8	1 3/8	3/16	1/4	1 9/16	1 5/8	1/8	1 1/2	1/16
15/16	7/8	1 7/16	1 13/16	1 3/4	1 7/16	3/16	1/4	1 5/8	1 11/16	1/8	1 5/8	1/16
1	15/16	1 1/2	1 7/8	1 3/4	1 1/2	1/4	5/16	1 3/4	1 13/16	3/16	1 5/8	1/8
1 1/16	1	1 9/16	1 15/16	1 7/8	1 5/8	1/4	5/16	1 7/8	1 15/16	3/16	1 3/4	1/8
1 1/8	1 1/16	1 5/8	2	1 7/8	1 11/16	1/4	5/16	1 15/16	2	3/16	1 3/4	1/8
1 3/16	1 1/8	1 11/16	2 1/8	2	1 3/4	1/4	5/16	2	2 1/16	3/16	1 7/8	1/8
1 1/4	1 3/16	1 13/16	2 5/16	2 1/8	1 7/8	5/16	3/8	2 3/16	2 1/4	3/16	2	1/8
1 5/16	1 1/4	1 15/16	2 7/16	2 1/4	2	5/16	3/8	2 5/16	2 3/8	3/16	2 1/8	1/8
1 3/8	1 5/16	2	2 1/2	2 1/4	2 1/8	5/16	3/8	2 7/16	2 1/2	3/16	2 1/8	1/8
1 7/16	1 3/8	2 1/16	2 9/16	2 3/8	2 1/4	5/16	3/8	2 9/16	2 5/8	3/16	2 1/4	1/8
1 1/2	1 7/16	2 1/8	2 5/8	2 3/8	2 3/8	5/16	3/8	2 11/16	2 3/4	3/16	2 1/4	1/8
1 9/16	1 1/2	2 3/16	2 11/16	2 1/2	2 1/2	3/8	7/16	2 7/8	2 15/16	3/16	2 3/8	1/8
1 5/8	1 9/16	2 3/8	3	2 5/8	2 5/8	3/8	7/16	3	3 1/16	3/16	2 1/2	1/8
1 11/16	1 5/8	2 7/16	3 1/16	2 3/4	2 3/4	3/8	7/16	3 1/8	3 3/16	3/16	2 5/8	1/8
1 3/4	1 11/16	2 1/2	3 1/8	2 7/8	2 7/8	3/8	7/16	3 1/4	3 5/16	3/16	2 3/4	1/8
1 13/16	1 3/4	2 9/16	3 3/16	3	3	7/16	1/2	3 7/16	3 1/2	1/4	2 13/16	3/16
1 7/8	1 13/16	2 5/8	3 1/4	3	3 1/8	7/16	1/2	3 9/16	3 5/8	1/4	2 13/16	3/16
1 15/16	1 7/8	2 11/16	3 5/16	3 1/8	3 1/4	7/16	1/2	3 11/16	3 3/4	1/4	2 15/16	3/16
2	1 15/16	2 3/4	3 3/8	3 1/8	3 3/8	7/16	1/2	3 13/16	3 7/8	1/4	2 15/16	3/16
2 1/16	2	2 15/16	3 9/16	3 1/2	3 1/2	1/2	5/8	4	4 1/8	1/4	3 1/4	3/16
2 1/8	2 1/16	3	3 5/8	3 1/2	3 1/2	1/2	5/8	4	4 1/8	1/4	3 1/4	3/16
2 3/16	2 1/8	3 1/16	3 13/16	3 5/8	3 5/8	1/2	5/8	4 1/8	4 1/4	1/4	3 3/8	3/16
2 1/4	2 3/16	3 1/8	3 7/8	3 5/8	3 3/4	1/2	5/8	4 1/4	4 3/8	1/4	3 3/8	3/16
2 3/8	2 5/16	3 3/8	4 1/8	3 7/8	3 7/8	1/2	5/8	4 3/8	4 1/2	1/4	3 5/8	3/16
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2 5/8	2 9/16	3 5/8	4 3/8	4 1/8	4 1/8	1/2	5/8	4 5/8	4 3/4	1/4	3 7/8	3/16
2 3/4	2 11/16	3 3/4	4 1/2	4 1/4	4 1/4	1/2	5/8	4 3/4	4 7/8	1/4	4	3/16

purposes they are quite frequently used. These bushings are not commonly used as removable bushings, as it would take considerable time to unscrew, and to again insert; a bushing of this type into the jig body.

Special Designs of Guide Bushings. — When the guide bushings are very long, and consequently would cause unnecessary friction in their contact with the cutting tools, they may be recessed, as shown in Fig. 13. The distance *A* of the hole in the bushing is recessed enough wider than the diameter of the tool so as not to bear on it. The length *B*, being about twice the diameter of the hole, gives sufficiently long guiding surfaces for the cutting tool, to prevent its running out. If the outside diameter of the bushing is very large compared with the diameter of the cutting tool, as indicated in Fig. 14, the expense of making the bushings may be reduced by making the outside bushing of cast iron, inserting into this a hardened tool-steel bushing, driven in place. The steel bushing is then given dimensions according to Table I for stationary bushings. The reason why there may be a necessity of a bushing having so large an outside diameter and so small a hole may be that the bushing is required to be removed for counterboring part of the small hole being drilled by a counterbore of large diameter, in which case the hole in the jig body has to be large enough to accommodate the large counterbore.

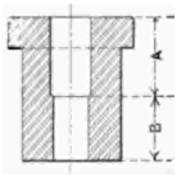


Fig. 13.

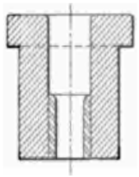


Fig. 14.

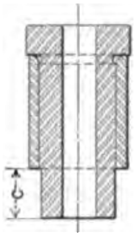


Fig. 15.

If a loose or removable bushing is longer than the lining bushing, as illustrated in Fig. 15, it will prove advantageous to have the diameter of the projecting portion of the bushing about $\frac{1}{32}$ inch smaller in diameter than the part of the loose bushing which fits the lining bushing. This lessens the amount of surface which has to be ground, and, at the same time, makes it easier to insert the bushing, giving it, so to say, a point, which will first enter the lining bushing, and it interferes in no way with the proper qualities of the bushing as a guide for the cutting tool.

In some cases, the holes in the piece to be drilled are so close to one another that it is impossible to find space for lining bushings in the jig. If this happens, it is necessary to make a leaf, or a loose wall, or the whole jig, of machine steel or tool steel, hardening a portion or the whole jig thus made.

Table V. Allowances for Grinding and Lapping Bushings

Operation	Diameter of Bushings in Inches					
	½	1	1½	2	2½	3
A	0.008	0.010	0.013	0.016	0.020	0.025
B	0.0005	0.0005	0.0007	0.0008	0.0009	0.001
C	0.008	0.010	0.013	0.016	0.020	0.025
D	0.0003	0.0005	0.0007	0.0008	0.0009	0.001

A—Grind outside; B—Lap outside after grinding; C—Grind inside; D—Lap inside after grinding.

Methods of Making Jig Bushings. — There are several methods followed in turning jig bushings. Some toolmakers prefer to "chuck out" the hole to the desired size and then finish the outside of the bushing by placing it on an arbor; others prefer to turn up the bushings two at a time, end to end, cut them apart, and then bore as the final operation. This is an excellent method to follow when making large bushings. The most rapid method, however, is to chuck out the hole and finish the outside at one setting, using bar stock held in the chuck of a rigid engine lathe. This method is not always practicable on large bushings.

In making allowances for grinding and lapping, many toolmakers use too small limits, which is the cause of many bushings having to be made over again on account of not "finishing out." On the other hand, many toolmakers leave too liberal an allowance for finishing, thereby causing unnecessary trouble and labor. The allowances given in Table V can be safely used when the bushings are made somewhere near the proportions indicated in Tables I to IV, but for extra long bushings more liberal allowances should be made.

Before hardening, the bushings should be plainly stamped with the size and purpose for which they are intended, "$\frac{15}{32}$ drill," "$\frac{1}{2}$ ream," etc. They should be stamped with a set of plain sharp figures, reserved solely for this purpose. It is poor practice to try to stamp the words "drill," "ream," etc., in a straight line, as this is difficult to do. If, however, the words are laid out on a slight curve the results are more satisfactory, as slight irregularities of alignment are not then so noticeable. Sharp clean figures and letters, neatly laid out, not only improve the appearance of the toolmaker's work, but also save the drilling operator's time, as sharp clean-cut figures can be read at a glance.

Hardening Jig Bushings. — When hardening bushings made of tool steel they should be brought to an even red heat in a clean fire; the heating should never be hurried. When bushings are heated quickly, they are apt to heat unevenly, which results in warping or distortion that makes it impossible to finish them to the required size. Gas furnaces are excellent for heating, but a clean charcoal fire will answer the purpose. As soon as the bushing has been brought to an even red heat, it should be dipped in water just warm enough to take off the chill. The bushing should then be heated to a "sizzling" heat, after which it is left in the air to cool. Some toolmakers draw bushings to a medium straw color. This is a mistake as it only tends to shorten their life.

Grinding and Lapping. — There are four methods in common use for finishing holes in jig bushings: 1. Lapping with a lead lap. 2. Lapping with a lead lap followed by a cast-iron or copper lap. 3. Internal grinding. 4. Internal grinding followed by a cast-iron or copper lap for removing the last 0.0005 inch. The first method is erroneous, as it invariably results in bell-mouthed holes, especially when the toolmaker charges the lap while in use, which is an unsatisfactory but very common method. The second method is correct for holes too small to be ground conveniently. The third method is inadvisable, as the grinding wheel, no matter how fine, leaves innumerable very fine scores and high spots. These high spots soon wear away leaving the hole oversize. The last method is correct and should be used whenever possible.

In Fig. 16 is shown a lead lap with a steel tapered spindle, and a convenient mold for casting the laps. This mold is provided with a base having a hole to receive the spindle that the lap is cast on. A number of laps can be cast in this mold at one heating of the metal, and the laps are afterwards turned to the size required. Fig. 17 represents a familiar form of cast-iron lap. This lap is split in three places and provided with a taper-end screw for expanding it to compensate for wear.

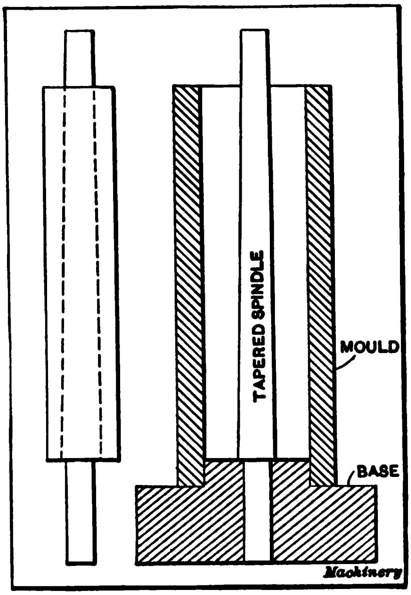


Fig. 16. Lead Lap and Mold used for Casting it

Laps should be charged before using — not while they are in use. A good way to charge a lap is to lay it on a cast-iron plate on which some of the abrasive material has been sprinkled. A cast-iron plate small enough to be conveniently handled is then held on the lap and moved back and forth with a regular motion. The lap being rolled between the two surfaces picks up a certain amount of the abrasive material. A lead lap can be charged in this manner very rapidly, as the grains of abrasive material readily imbed themselves in the soft metal. A cast-iron lap, being of a harder material, requires more time to properly charge.

Until the last few years emery was the abrasive generally used for lapping. At the present time, however, artificial abrasives, products of the electric furnace, are displacing emery, as they cut faster, producing excellent results in a comparatively short time as compared to emery. Nos. 90 to 150 are used in connection with lead laps for roughing operations. For the final finishing with cast-iron laps, flour abrasive is used. When not in use, any abrasive used for lapping should be kept in a covered box to protect it from dirt and other foreign substances. A small chip or piece of grit will often cut a deep score in a piece of work.

Laps should always be run at a fairly low speed. Fifteen to twenty feet surface speed for a lead lap used for roughing and twenty to twenty-five feet surface speed for a cast-iron lap used for finishing are about right. A high surface speed causes the lap to wear out without cutting as rapidly as it should. Many toolmakers make the mistake of running laps too fast, often causing unsatisfactory work. For light lapping, the work can be held by hand, but for a heavy roughing cut it is best to hold the work with an ordinary lathe dog, care being taken to see that the dog is not clamped so tightly as to spring the work out of shape. Lead laps should be split to compensate for wear, and the spindles should have a groove cut along their entire length to prevent the lap from turning.

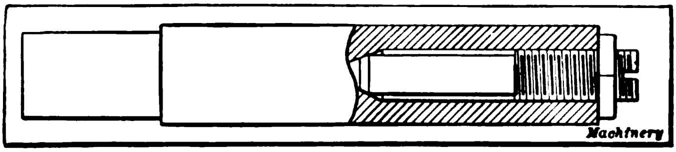


Fig. 17. Usual Form of Cast-iron Lap

Before testing with a size plug, the work should be washed with benzine or gasoline to remove all traces of the abrasive material, a few grains of which will wear the size plug below standard size in a surprisingly short time.

Many toolmakers look on the finishing of jig bushings by internal grinding as a rather uncertain method, whereas it is a comparatively simple process when the following important factors are carefully considered. First, proper selection of grinding wheels; second, correct wheel speeds or at least as nearly correct as the design of the machine will permit; third, correct alignment of the headstock in regard to the travel of the platen; and fourth, proper truing of wheels.

Wheels for internal grinding should be of a medium grit, soft grade and open bond. As a rule the grit should never be finer than 60 grit; in fact, a coarser grit can often be used to advantage. Wheels with fine grit cut slowly, and fill up readily, glazing and invariably heating the work, and causing chattering and other troubles. In fact, the only argument in favor of a fine grit wheel is that it leaves a smooth surface. However, no matter how smooth the surface appears, even under a powerful glass, it must be lapped to remove the wheel marks.

For the internal grinding of jig bushings, aloxite wheels, 1½ inch in diameter, ⅜-inch face, 60 grit, P grade, D-495 bond, may be used with good results, the wheel speed being 12,000 R.P.M. For bushings averaging 2½ inches long, 1¾-inch hole, the holes rough-bored, 0.015 inch being left for grinding, the grinding time per bushing, including chucking and truing up, would be about twelve minutes each, and the finish left good, 0.0005 inch being sufficient to lap out the wheel marks. Reference is made to the holes being rough-bored; this is good practice, as the rather rough surface tends to wear the wheel just a little while removing the fire scale, thus preventing the wheel from glazing. Once the scale is removed from the hole, the wheel should not glaze readily, provided it is of the proper grit and grade.

Wheels for internal grinding should be run at a surface speed of 5000 feet per minute. This, however, is a general rule open to exceptions. A safe practical rule to follow is to speed up the wheel if it wears away too readily, and to reduce the speed where the wheel shows a tendency to glaze. Attention to this rule will often save much trouble. The toolmaker should bear in mind the fact that it is easier to adjust the speed to suit the wheel than it is to try to keep on hand a large variety of wheels to suit all speed conditions.

Assuming that the work in question is to be done on an ordinary universal grinder, the headstock must be set parallel with the travel of the platen to produce straight holes. A practical way to determine parallelism is to clamp a piece of round stock in the headstock chuck, letting it project from the jaws a little farther than the length of the holes to be ground. This piece should have a groove turned in it for the wheel to dwell in during reversal. This test piece is then ground in the regular way with the wheel used for cylindrical work, the headstock being adjusted by means of its swivel base until the test piece is ground parallel. Before calipering, the wheel should be allowed to grind until very few sparks are visible. When once this test piece has been ground straight the setting can be depended upon to produce straight holes, provided, of course, that the swivel adjustment of the headstock and the angular adjustment of the platen are not disturbed. To try to align the headstock by calipering the work while the internal grinding is in process is, at best, difficult, and the operator is never sure of accurate results.

It is common practice to true wheels for internal grinding with a diamond fed by hand, using the eye as a guide. This is poor practice, as the wheel is seldom turned parallel, one edge being left to do all the cutting, which glazes it readily. A more practical way to true these comparatively soft wheels is to feed them past the end of a carborundum rub, in 20 grit, H grade. The rub can be held in a suitable holder strapped to the platen of the grinder or held firmly by hand against the end of the work. A carborundum rub shows high efficiency when used for this purpose.

In holding work in the chuck for internal grinding, it is well to exercise due care to see that the work is not clamped hard enough to spring it out of shape. As a rule it does not require much pressure to hold work of this nature, as the grinding cut is comparatively light. As it is general practice to grind internal work dry, a certain amount of expansion from frictional heat is always present. For this reason considerable care has to be used in calipering the work with the sizing plug. As the plug is many degrees cooler than the work, it is liable, on being inserted, to contract the bushing suddenly, causing bushing and plug to "freeze" together firmly. This can be avoided by cooling the work with a plug that is known to be undersize before calipering with a plug of the desired size.

When a wheel of 60 grit is used, a hole one inch or under in diameter should be left approximately 0.0005 inch undersize. This amount is sufficient to lap out the wheel marks and leave a "dead smooth" mirror finish to the hole. This is a general rule based on the fact that a certain amount (in this case 0.00025 inch) is enough allowance to lap out the marks left on a surface by a grinding wheel, and that should suffice for all holes regardless of size. With comparatively large holes, one and one-half inch diameter or over, it is better, however, to make allowance for finishing, owing to the fact that the area of contact of wheel and work is generally not so great and the ground surface is not quite so smooth.

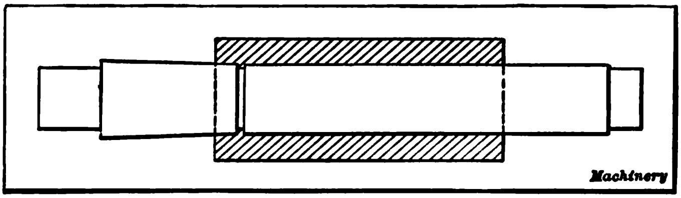


Fig. 18. Arbor for Holding Bushings

In regard to the external grinding of bushings, there are two important points that should be given consideration: the selection of wheels and the method of holding the work. The wheel should be fast cutting and at the same time it should hold its shape and leave a good finish. For this work good results may be obtained with an aloxite wheel of 12 inches diameter, ½-inch face, 5-inch hole, 405 grit, N grade, D-497 bond, the wheel being run at a speed of 1800 R.P.M.

When a number of bushings are to be ground one after another it is best to mount them on arbors of the same length, when practicable to do so, thus saving considerable time generally spent in re-setting the platen, which has to be done whenever the tailstock is moved to accommodate arbors of different lengths. An arbor for holding bushings should be made as shown in Fig. 18. The straight part should be a good fit in the bushing, a slight taper on the remainder of the arbor being sufficient to prevent the bushing from turning on the arbor. When bushings are held on an ordinary arbor or mandrel the operator is never quite sure that the hole and the outside of the bushing are concentric, as one end of the arbor, owing to its taper, does not quite fill the hole. This is illustrated in Fig. 19. Both Figs. 18 and 19 are somewhat exaggerated to illustrate the principle.

In grinding lining and solid bushings, due allowance must be made for a driving fit in the body of the jig. There are three methods in common use for making driving fits on this class of work: First, grinding the bushing until the lower end just enters the hole, the bushing being slightly tapered to bring it to a snug fit when pressed into place; second, grinding the bushing straight for its entire length, leaving it just enough oversize to make a good driving fit; and third, grinding the bushing for nearly its entire length just enough oversize to make a good driving fit, and grinding about one-eighth its length just enough undersize to enter the hole.

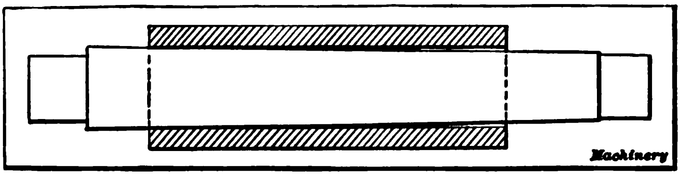


Fig. 19. Improper Fit of Bushing on Ordinary Arbor

The first method is not considered very good practice, as the bushing contracts more at the top than elsewhere, owing to the taper, which leaves the hole in the bushing tapered. The second method is very poor practice, as the bushing is liable to cramp while being forced in place, which results in an unsatisfactory job, as the hole in the jig is generally sheared by the sharp end of the bushing. The third method is correct, as the part that is ground to fit the hole acts as a pilot, thus insuring the proper starting of the bushing, and the body, being straight, insures even contraction.

In making allowances for driving fits, 0.001 inch for each inch diameter of the bushing is considered practical where the holes are one inch or over, and where the holes in the jig are bored smooth. If the holes are rough-bored, a more liberal allowance is required. After the lining bushings are driven in place, they require re-lapping, as they always contract a little.

The outside of the removable bushings should be finished by lapping to a "dead smooth" finish, as otherwise they will soon wear loose. This should never, under any circumstances, be done with emery cloth, but with a cast-iron lap as illustrated in Fig. 20. The abrasive used in this case should be of flour grit with lard oil as a lubricant, the abrasive and oil being applied through a hole in the top of the lap. The work should be lapped with a regular even motion to insure its being straight, and should be brought to the temperature of the room by being cooled in benzine or gasoline before testing for a fit. The lapping should be carried to a point where the bushing is a wringing fit in its liner, but not tight enough to stick when left for a moment.

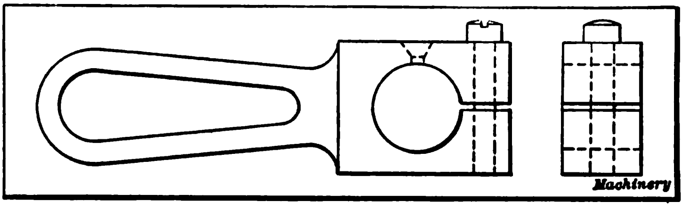


Fig. 20. Lap for Finishing Outside of Slip Bushings

After the grinding and lapping of the removable bushings, their tops can be finished by lapping on a carborundum stone, in medium grit, wet with gasoline. A regular motion should be used across the face of the stone without turning or altering the relative position of the bushing. This lapping gives the bushings a good appearance, and, as the dimensions stamped are left black from the action of the fire in hardening, they can be read at a glance.

CHAPTER IX

LOCATING POINTS AND ADJUSTABLE STOPS

The locating points in a jig usually consist of finished pads, bosses, seats, or lugs, cast solid with the jig, as illustrated in Fig. 1. In this engraving the surfaces marked *f* are the locating points, which bring the piece to be machined in correct relation to the bushings guiding the drills, or to the gages to which other cutting tools may be set. This method of locating the work is satisfactory when the work done is finished in a uniform way and where there is very little variation in the parts inserted in the jig.

Pins and Studs used as Locating Means. — Another commonly used method for locating the work in jigs is by means of dowel pins, as shown at *A* and *B* in Fig. 2. The sides of the dowel pins which rest against the work are usually flattened, as indicated, so as to give more bearing than a mere line contact with the pins could give, and, at the same time, prevent too rapid wear on the locating pins, as would be the case if the work bear against the pins along a line only.

Sometimes pins or studs are inserted in jigs to act as locating points, instead of having lugs cast directly on the jig as shown in Fig. 1. A case where a pin is used for this purpose is shown in Fig. 3, where *B* is the body of the jig, *A* the pin inserted to act as a locating and resting point, and *C* the work located against this point. Locating pins of this character should always be provided with a shoulder or collar, so that they will firmly resist the pressure of the work they support, without possibility of moving in the hole in which they are inserted.

Locating by Means of V-blocks. — A common method of locating cylindrical pieces or surfaces is that of placing the cylindrical surface in a V-block, as shown in Fig. 4. This V-block, as a rule, is stationary, and is held in place by screws and dowel pins, as indicated in the engraving, but sometimes this V-block may also be made adjustable, in order to take up the variations of the pieces placed in it, and also in order to act as a clamp. A V-block of this character is shown in Fig. 5. In this, *A* is the adjustable V-block, having an oblong hole *B* to allow for the adjustment. The block is held down in place by a collar-head screw *C*, which passes through the elongated hole. The under side of the block is provided with a tongue *D*, which enters into a slot in the jig body itself, the V-block being thereby prevented from turning sideways. The screw *E* passes through the wall of the jig, or through some lug, and prevents the V-block from sliding back when the work is inserted into the jig. It is also used for adjusting the V-block and, in some cases, for clamping the work. The V-blocks are usually made of machine steel, but when larger sizes are needed they may be made of cast iron. Little is gained, however,

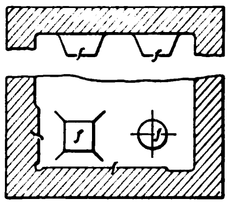


Fig. 1. Locating Pads in Jigs

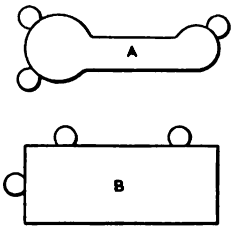


Fig. 2. Pins used for Locating Work

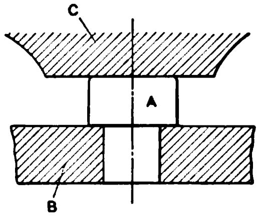


Fig. 3. Inserted Pin used for Locating and Supporting Work

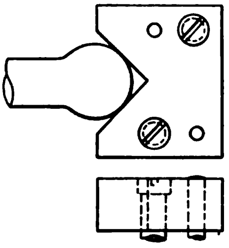


Fig. 4. V-block for Locating Round Work or Cylindrical Surfaces

in making these blocks of cast iron, as most of the surfaces have to be machined, and the difference in the cost of material on such a comparatively small piece is very slight.

Cup and Cone Locating Points. — When it is essential that a cylindrical part of the work be located centrally either with the outside of a cylindrical surface or with the center of a hole passing through the work, good locating means are provided by the designs shown in Figs. 6 and 7. In Fig. 6, the stud *A* is countersunk conically to receive the work. The stud *A* is made of machine or tool steel, and may, in many cases, serve as a bushing for guiding the tool. In Fig. 7, the stud is turned conically in order to enter into a hole in the work. These two locating appliances are always made stationary, and are only used for locating the work, never for binding or clamping.

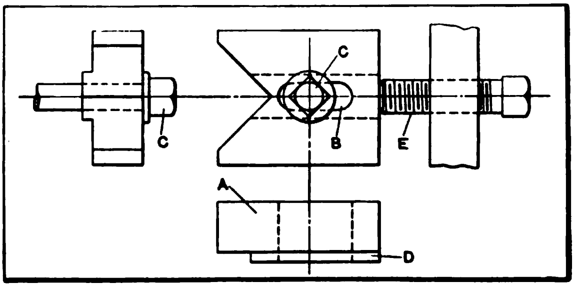


Fig. 5. Adjustable V-block used for Locating Purposes

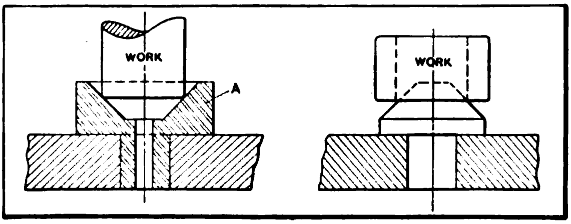


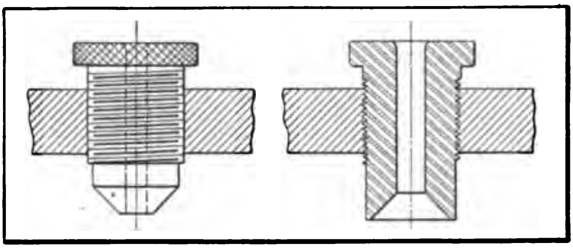
Fig. 6. Recessed Stud used for Locating Round Work in a Jig with Relation to the Center

Fig. 7. Conical Stud used for Locating Work in Relation to the Center of a Hole

Screw Bushings and Sliding Bushings used as Locating Means. — Screw bushings may be used for locating and clamping purposes by making them long enough to project through the walls of the jig and by turning a conical point on them, as shown in Fig. 8, or by countersinking them, as shown in Fig. 9. In all cases where long guide bushings are used, the hole in the bushing ought to be counterbored or recessed for a certain distance of its length.

Another type of bushing which serves the same purpose as a screw bushing is illustrated in Fig. 10. This bushing, together with the forked lever *D* and clamping bolt and wing-nut shown, will serve not only to locate but also to clamp the work in place. This sliding bushing gives very good results and is preferable to the screw bushing in cases where accurate work is required; but, as a rule, where extreme accuracy would be required, this kind of locating means is not used.

In Fig. 10 the sliding bushing *A* has a close sliding fit in the lining bushing *B*. In the head of the bushing *A* there are two screws with hardened heads, which fit into elongated slots in the forked lever or yoke *D*, which, in turn, swivels around pin *E*. The eye-bolt *F* fits into a slot *G* in the yoke, and the wing-nut tightens down the bushing against the work as clearly indicated in the engraving. A comparatively long bearing for the bushing is required in order to produce good results. On work that varies considerably in size, this arrangement works somewhat quicker than does a screw bushing, but it is clearly evident that it is a rather expensive appliance and that the construction of the jig does not always permit of its application.



Figs. 8 and 9. Screw Bushings

In some instances it is necessary to have the screw bushing movable sideways, for instance, when the piece of work to be made is located by some finished surfaces, and a cylindrical part is to be provided with a hole drilled exactly in the center of a lug or projection, the relation of this hole to the finished surfaces used for locating being immaterial. The piece of work, being a casting, would naturally be liable to variations between the finished surfaces and the center of the lug, particularly if there are other surfaces and lugs to which the already finished surfaces must correspond, and in such a case, the fixed bushing for drilling a hole that ought to come in the center of the lug, might not always suit the casting. In such a case, so-called "floating" bushings, as shown in Fig. 11, are used. The screw bushing *A* is conically recessed and locates from the projection on the casting. It is fitted into another cylindrical piece *B*, provided with a flange on one side. The piece *B*, again, sets into the hole *C* in the jig body *D*, this hole being large enough to permit the necessary adjustment of the jig bushing.

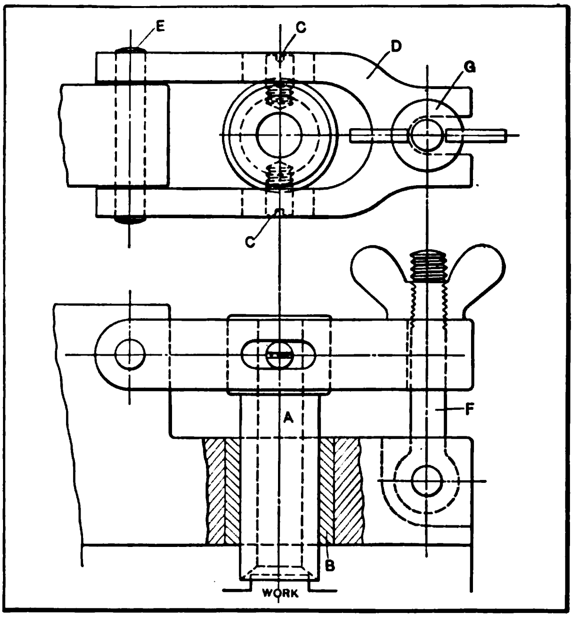


Fig. 10. Sliding Bushing for Locating and Clamping Work

When the bushing has been located concentric with the lug *E* on the work, the nut *F*, having a washer *G* under it, is tightened. The flange on piece *B* and the washer *G* must be large enough to cover the hole *C* even if *B* is brought over against the side of the hole. It is not often necessary, however, to use this floating bushing, because it is seldom that a drilled hole in a piece of work can be put in without having any direct relation to other holes or surfaces.

Adjustable Locating Points. — The most common form of adjustable locating points is the set-screw provided with a check-nut, as shown in Fig. 12. The screw *A* is a standard square-head set-screw, or, in some cases, a headless screw — with a slot for a screw driver; this screw passes through a lug on the jig, or the jig wall itself, and is held stationary by a check-nut *C* tightened up against the wall of the jig. Either end of this screw may be used as a locating point, and the check-nut may be placed on either side. By using a square-head screw, adjustment is very easily accomplished, but unless the operator is familiar with the intentions of the designer of the jig, locating

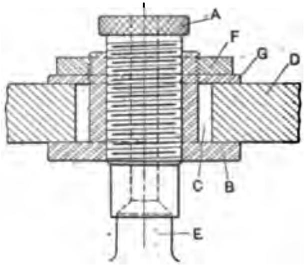


Fig. 11. Floating Drill Bushing

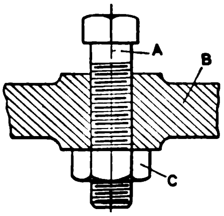


Fig. 12. Adjustable Locating Point

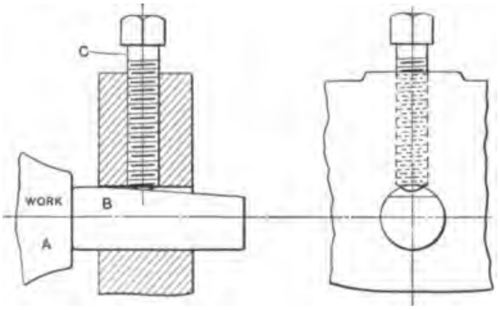


Fig. 13. Adjustable Locating Point consisting of a Flatted Stud held in Place by a Set-screw

points of this kind are often mistaken for binding or clamping devices, and the set-screws are tightened up and loosened to hold and release the work, when the intention is that these screws should be fixed when once adjusted. It is not even possible to depend upon the check-nut stopping the operator from using the screw as a binding screw. A headless screw, therefore, is preferable, as it is less apt to be tampered with.

The sliding point, as illustrated in Figs. 13 and 14, is another adjustable locating point which is used to a great extent in jig work. A flat piece of work or a plate which is not perfectly level will always rock if put down on four stationary locating points, but the difficulty thus encountered is very easily overcome by making one of the locating points adjustable, and, as a rule, the sliding point is used for this purpose.

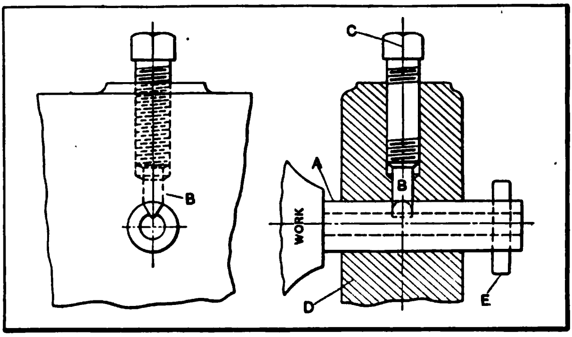


Fig. 14. Sliding Point used for Locating Work

One design is shown in Fig. 13, where *A* represents the work to be located, *B* the sliding point itself, and *C* the set-screw, binding it in place when adjusted. The sliding point *B* fits a hole in the jig wall and is provided with a milled flat slightly tapered, as shown, to prevent its sliding back under the pressure of the work or the tool operating upon the work. This design of sliding point is frequently used, but it is not as efficient as the one illustrated in Fig. 14. In this design the sliding point *A* consists of a split cylindrical piece, with a hole drilled through it, as illustrated in the engraving, and a wedge or shoe *B* tapered on the end to fit the sides of the groove or split in the sliding point itself. This wedge *B* is forced in by a set-screw *C*, for the purpose of binding the sliding point in place. Evidently, when the screw and wedge are forced in, the sliding point is expanded, and the friction against the jig wall *D* is so great that it can withstand a very heavy pressure without moving. Pin *E* prevents the sliding point from slipping through the hole and into the jig, when loosened, and also makes it more convenient to get hold of. In the accompanying table are given the dimensions most commonly used for sliding points and binding shoes and wedges.

Special Types of Adjustable Stops. — Adjustable stops are used to a greater extent in milling fixtures than in drill jigs, but the principles employed are the same. The examples shown in connection with the following description of adjustable stops have been applied to milling fixtures, and, in some cases, to drill jigs. In Fig. 15 is shown the simplest type of adjustable stop, provided with a helical spring beneath the plunger, to press it against the work. The objection to this type of stop is that the plunger *A* will slip back under the pressure of the clamps or cutting tools upon the work. There is also danger of the milled flat on the plunger clogging with dirt, so that the stop will not work properly. Considerable time is, therefore, lost in using jigs or fixtures with this type of stop. The method of clamping the plunger is also slow, as it is necessary to use a wrench in tightening or loosening the set-screw *B*. In Fig. 16 is shown an adjustable stop which is an improvement over that shown in Fig. 15. The flat on the side of plunger *A* is milled at a slight

Dimensions of Sliding Points and Shoes or Binders

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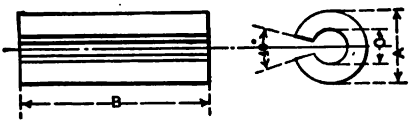
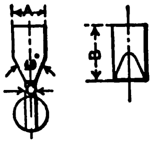
<tr><td colspan="5" rowspan="2"> </td><td colspan="3"> </td></tr>
<tr><td>Screws</td><td>$\frac{5}{16}$</td><td>$\frac{3}{8}$</td></tr>
<tr><td>A</td><td>$\frac{3}{8}$</td><td>$\frac{1}{2}$</td><td>$\frac{5}{8}$</td><td>$\frac{3}{4}$</td><td>A</td><td>$\frac{1}{4}$</td><td>$\frac{9}{32}$</td></tr>
<tr><td>B</td><td>$2\frac{1}{4}$ to 3</td><td>$2\frac{1}{4}$ to 3</td><td>$2\frac{1}{4}$ to 3</td><td>$2\frac{1}{4}$ to 3</td><td>B</td><td>$\frac{1}{2}$</td><td>$\frac{5}{8}$</td></tr>
<tr><td>C</td><td>$\frac{3}{16}$</td><td>$\frac{1}{4}$</td><td>$\frac{5}{16}$</td><td>$\frac{3}{8}$</td><td>C</td><td>$\frac{1}{16}$</td><td>$\frac{3}{32}$</td></tr>
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angle instead of parallel with the center-line, as in Fig. 15. This prevents the plunger from slipping after being clamped. A piece of hardened drill rod *B*, which is kept from turning by a small pin *C*, engaging a flat milled in piece *B*, is used between the plunger *A* and the clamp. A wing-nut *D* is fastened to the end of the screw as shown, in order to eliminate the use of a wrench.

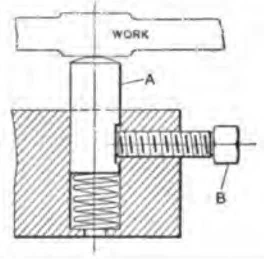


Fig. 15. Simple Type of Adjustable Stop

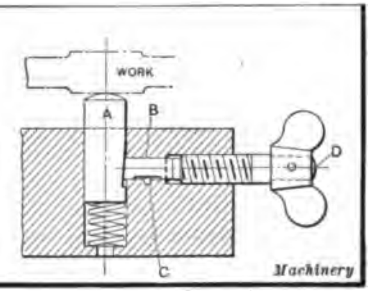


Fig. 16. Improvement on Stop shown in Fig. 15

In Fig. 17 is shown another adjustable stop which presents a further improvement over that shown in Fig. 16. A bronze bushing *B* is driven into the base of the jig and allowed to project above the base, as indicated. Plunger *A* is a sliding fit in the bushing. A cap *C* is driven onto the end of the plunger and extends down over the outside of the bushing, as indicated, making the stop dirt-proof. This stop, however, as well as that shown in Fig. 16, is not entirely satisfactory, because it will

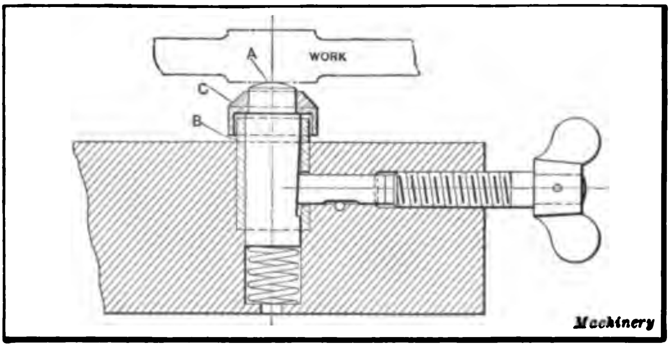


Fig. 17. A Further Improvement upon the Adjustable Stops shown in Figs. 15 and 16

shift at the time it is tightened, although when once tightened it will remain in position.

In Fig. 18 a different arrangement is shown. Here the thumb-screw and spring plunger used in the preceding device is abandoned, and the sliding wedge *A* is used to obtain the pressure upon plunger *C*. The wedge is provided with a handle *B* attached so that it can easily be operated, and is held in place by two shoulder screws that are inserted through two elongated slots milled in the wedge. These screws are tightened after the stop has been brought up to position. The difficulty met with in using this stop is that the wedge is liable to slip back, owing to the vibration of the machine while in operation, so that plunger *C* drops down.

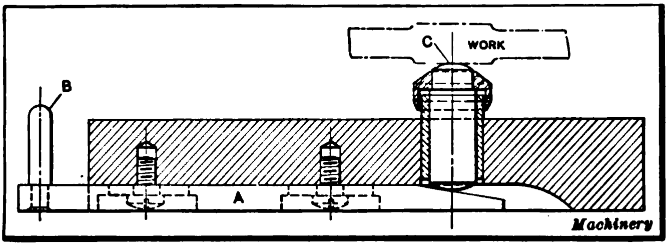


Fig. 18. Simple Form of Adjustable Wedge Stop

In Fig. 19 is shown a further development of the method indicated in Fig. 18. In this case, means are provided for preventing wedge *A* from slipping back. A stud is riveted into the wedge *A*, this stud extending up through an elongated slot cut in the base of the fixture. The end of the stud is threaded for the knurled nut *B*, which also acts as a handle for shifting the wedge. When this nut is tightened, it clamps the wedge *A* and the shoe *C* against the base. The friction between shoe *C* and the base prevents the slipping of wedge *A*. Shoe *C* also acts as a covering for the slot cut in the base, and thus acts as a dirt and chip shield. It is prevented from turning, when the nut *B* is tightened or loosened, by a stud *D*, driven into it and sliding in a slot cut in the base. The difficulty with this design is that wedge *A* rests upon the table of the machine, and, if there is slight unevenness in the table, the plunger is liable to spring down slightly under the pressure of the cut.

In order to overcome this difficulty, an adjustable stop, as shown in Fig. 20, has been designed. The flat style of wedge is abandoned, and the wedge *A* is made of drill rod and slides in a hole drilled in the base of the fixture. The stud at the back end of the wedge is screwed into it instead of being riveted, as in the previous example. Bushing *C* is provided with a shoulder and a headless set-screw *D* is added to prevent plunger *E* from dropping out when the fixture is not in use. The wedge *A* is subjected to considerable friction and the fixture is, therefore, not so sensitive to the touch of the operator as would be desirable. It is difficult for the operator to feel when the stop is against the work, when tightening the wedge in position.

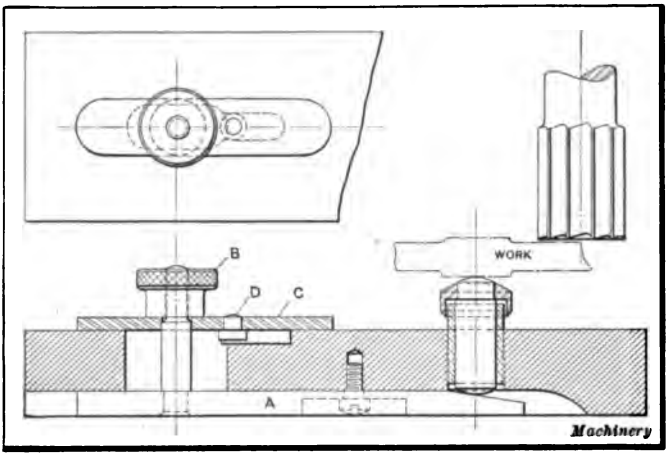


Fig. 19. Improvement upon the Adjustable Wedge Stop shown in Fig. 18

Fig. 21 shows a modification of the design shown in Fig. 20, the only change made being in bushing *A*, which has been lengthened so that it will act as a support for the end of wedge *B*. The bushing is made of cold-rolled steel and casehardened. The bottom part of the base is cut away in order to reduce the friction between the base and the wedge. This design is better than that shown in Fig. 20.

In Fig. 22 is shown a somewhat complicated and expensive adjustable stop which, however, has the advantages of almost perfect operating conditions. Bushing *A* is lengthened and has a much larger shoulder in order to take the thrust to which it will be subjected when the device is operated. A small pin *B* replaces the headless set-screw used in the designs in Figs. 20 and 21. The arrangements for clamping the wedge have been considerably changed, and bronze casting *C* is added. A hole is cut in the base into which the casting is inserted, clearance being permitted all around so that the casting can be aligned easily with the wedge. The casting is held in place by two fillister-head screws and two dowels; a hole is drilled through the lower part of it which acts as a support for the back end of the wedge, as indicated. The front end is supported in the bushing *A* in such a manner that the friction is reduced to a minimum. Casting *C* also supports the shoe *D* and raises it from the base of the fixture. A tongue is cut on the lower side of shoe *D* which fits into a groove in casting *C*, thereby preventing the shoe from turning when the nut is tightened or loosened. Stud *E* is screwed into the side of the knurled nut and a small pin *F* is driven into the shoe. This pin acts as a stop for the

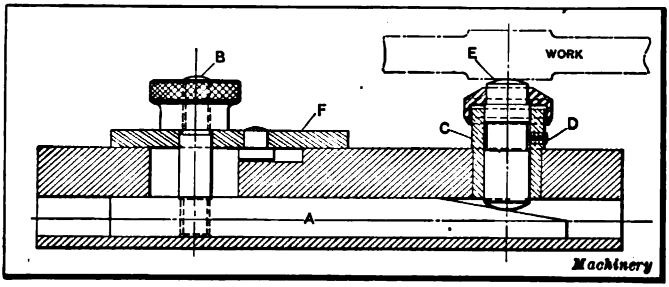


Fig. 20. A Further Improvement upon the Adjustable Wedge Stops shown in Figs. 18 and 19

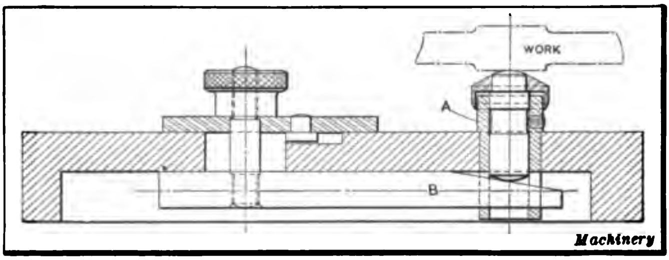


Fig. 21. A more Satisfactory Form of Adjustable Wedge Stop than that shown in Fig. 20

stud, preventing the operator from turning the nut more than is necessary in tightening or loosening.

The adjustable stop shown in Fig. 22 meets practically all requirements placed on an adjustable stop. It will not slip back under the pressure of the stop; it will not slip in tightening; it is dirt-proof; all the parts form integral parts of the jig; and it will not become loose, due to vibration of the machine, or spring down under the pressure of the cut, due to unevenness of the tables of the machines on which the fixture is used. It can be rapidly operated and is so sensitive that the operator feels instantly when plunger *G* is in contact with the work.

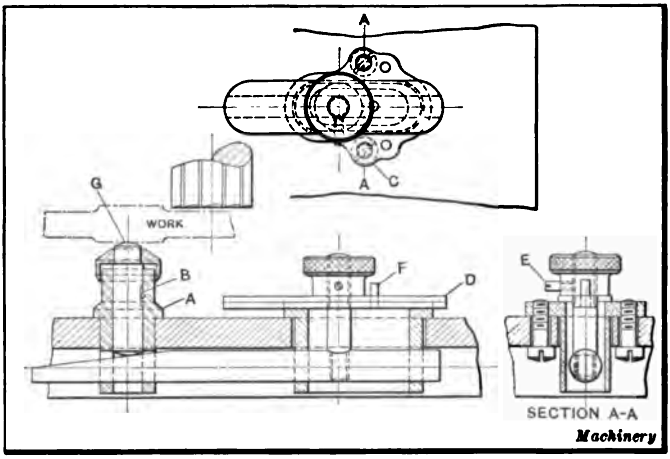


Fig. 22. Principle of the Final Improvement in the Adjustable Wedge Stop

The only objection to this design is that so much of the metal of the base has been cut away that it is seriously weakened, and the design shown in Fig. 23 is superior in this respect. In the making of the fixture, difficulties were also encountered in aligning the holes in bushing *A* with the holes in casting *C*, Fig. 22. This was remedied by making the bushing an easy fit and adding a small pin *D* and the round-head screw *C*, Fig. 23, to keep the bushing from turning or working loose. The wedge was also jointed and made in two parts, as indicated, in order to take care of the variations that might occur in drilling the holes in the bushing *A* and casting *C*, Fig. 22, in which the wedge slides. This practically makes the wedge self-aligning.

Locating from Finished Holes. — If the work to be finished in the jig has some holes already finished, it is sometimes most satisfactory to locate the work by these holes, which may be done by means of studs or plugs similar to the one shown in Fig. 3, which then enter the holes; preferably, these studs should be ground and hardened to the standard size of the hole. If the finished hole should be of a character that varies somewhat in size, expansion studs with bushings may be used. These studs may be of a great many different designs and styles, but, as a rule, they always work on the same principle as the one shown in Fig. 24. In this, *A* is the bushing, fitting the finished hole in the work. This bushing is split in several different ways, either by having one slot cut entirely through it, and two more slots cut to within a short distance of the outside periphery, or by having several slots cut from the top and from the bottom, alternating, but not cut entirely through the full length of the bushing. The method of splitting, however, in every case, accomplishes the same object, that of making the bushing capable

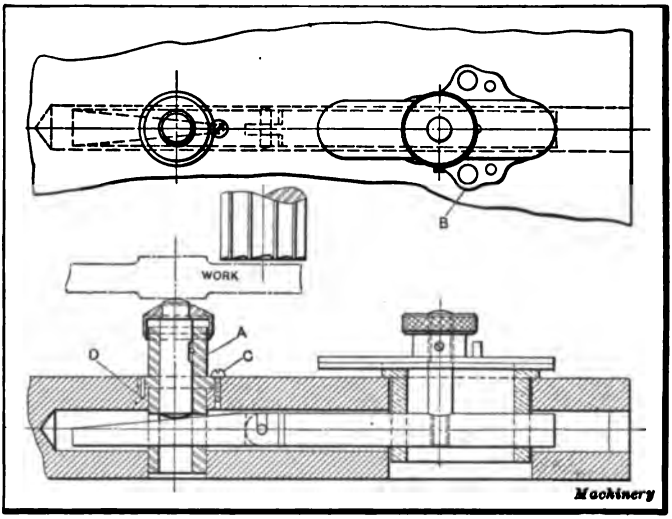


Fig. 23. The Adopted Form of Adjustable Wedge Stop

of expansion, so that when the stud *B*, which is turned to fit the tapered hole in the bushing, is screwed down, the bushing is expanded.

Locating by Keyways in the Work. — Sometimes the work to be finished in the jig is provided with a keyway or a slot, or with some other kind of a seat, by means of which it is located on its component part on the machine for which it is ultimately intended, and it is always essential that the work be located in the same way in the jig as it is to be located on the machine on which it is to go; thus, if the work has a keyway suitable for locating, a corresponding keyway ought to be put into the jig, and the work located by means of a key, as shown in Figs. 25 and 26. Instead of a loose key, a tongue may be planed or milled solid with the jig, but, as a rule, it is more satisfactory to have the loose key, as, if it should happen to wear, it is possible to replace it; and if the width of the keyway should vary in different lots of the parts made, it is possible, with little expense, to make a new key to fit the variation, whereas if the key is made solid with the jig, and found to be either too large or too small, the trouble of fixing this would be considerably greater.

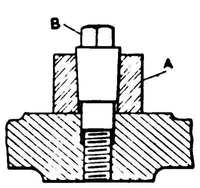


Fig. 24.

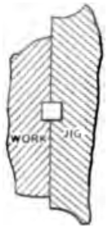


Fig. 25.

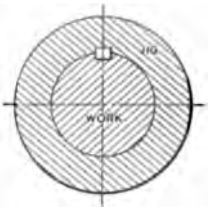


Fig. 26.

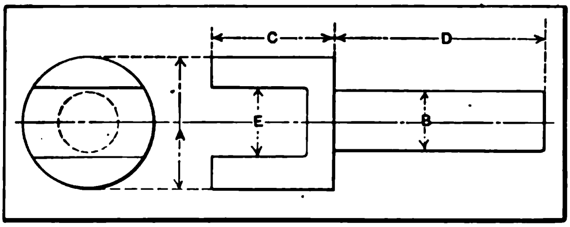


Fig. 27. Work which is Milled as Indicated at E

Common Defects in Jig Design. — The first consideration of the jig designer should be to determine what degree of accuracy is essential in the part that is to be produced, and also whether absolute interchangeability is necessary. This information will be a guide for the economical production of the jig. The designer must also consider any operations which are to be performed on the work prior to the one for which the jig under consideration is intended; for while this preliminary machining may not need to be accurately done, inaccuracy or uniformity may result in improperly locating the work in the next jig, which should be so designed as to locate the part with the required accuracy.

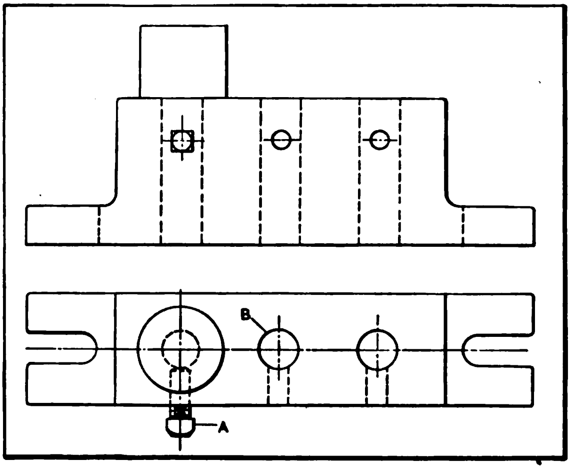


Fig. 28. Defective Design of Fixture for Holding Piece shown in Fig. 27

The locating points of any jig should be such as to allow as wide a range of inaccuracy on any preceding operation as is compatible in the part. For example, if the part has to be turned to, say, a limit of 0.001 inch, it will require more skill and time than if a limit of 0.005 inch is allowable. Again, as far as practicable, the portion of the work that requires to be the most accurate should be used in locating it in the jig for the succeeding operation. Often a surface is selected to locate from, which, in consequence, must be machined to an accurate limit, when accuracy otherwise would be unnecessary. This, of course, only adds to the cost of production. After considering the points mentioned, the best method of arranging the details of the jig, so that it has as few dimensions as possible requiring absolute accuracy, should also receive attention; that is, the jig should be as simple as possible, and still be so designed as to accurately locate the parts to be machined.

In Figs. 28 and 29 are shown two jig designs which will serve to illustrate these points. The part for which a jig is required is shown in Fig. 27. In the preliminary machining operation the work is turned to diameters *A* and *B* and to lengths *C* and *D*. The limit of accuracy required on end *A* is $-\frac{1}{64}$, or any diameter from $1\frac{39}{64}$ inch as a minimum to $1\frac{5}{8}$ inch. For end *B* a finer limit of −0.002 is necessary, so that this end should be used as the locating part for the next operation; *viz.*, the milling out of the slot *E* which must be central with the part *B*. A design such as shown in Fig. 28 is not uncommon for this operation, and with it fairly accurate results will be secured; but if the locating diameter on the work is slightly small, say 0.002 inch, then the forcing of the piece over to one side by the locking screw *A* will result in an inaccuracy in the milling operation. The locating holes *B* must be the exact size of the locating part of the work, and unless every piece is a push fit (which is un-

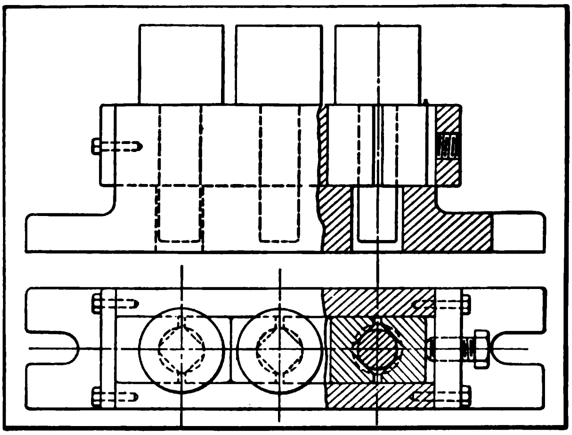


Fig. 29. Fixture which will hold a Number of Pieces, Fig. 27, properly, even when Diameters of Locating Parts vary

necessary accuracy in the part) the location is not accurate, as the work is clamped against a small area on one side of the hole and the point of the set-screw on the other. This can be avoided by locating the part against V-blocks, as shown in Fig. 29, which locate each shank central, irrespective of the variations in their diameters. The construction of this jig illustrates the points which have been referred to. The V-blocks provide four lines of contact, and the part is secured very rigidly in a central position irrespective of the variations in the diameter of the locating part. This jig, though more expensive than the one shown in Fig. 28, is quite simple in its construction. A central slot is machined to a width which need not be to any particular dimension as the steel V-blocks will be accurately fitted to this slot. Steel plates are secured to the ends of the jig after machining the slot as shown. By closing these ends after the slot is machined, the tool has a clear passage through, which, of course, would be impossible were the ends cast on. The V-blocks are planed in one piece, as shown in Fig. 30. The only important dimension is the width of the block. The exact position of the V in relation to the sides is immaterial provided that after the blocks have been sawed off they are inserted in the slot in the jig with the long or short sides together. To avoid trouble from this source, one side of the slot and a corresponding side on the blocks should be marked to insure the correct insertion of the latter. In the event of a design requiring the V's to be strictly central with the sides, the cost would, of course, be increased, as much more care would be required in machining. The jig shown in Fig. 29 is for holding three of the pieces shown in Fig. 27 at one time; this number could be increased as desired.

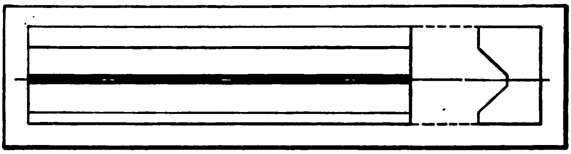


Fig. 30. The Way the V-blocks for the Jig, Fig. 29, are planed

CHAPTER X

JIG CLAMPING DEVICES

The clamping devices used in connection with jigs and fixtures may either clamp the work to the jig or the jig to the work, but very frequently the clamps simply hold in place a loose or movable part in the jig, which can be swung out of the way to facilitate removing the work from, and inserting it in, the jig. The work itself is in turn clamped by a set-screw or other means passing through the loose part, commonly called the leaf.

Types of Clamps. — The simplest form of clamping device is the so-called clamp, of which a number of different forms are commonly used. Perhaps the most common of all clamps is the one shown in Fig. 1. This kind of clamp is also commonly termed a strap. It is simple, cheap to make, and, for most purposes, it gives satisfactory service. The clamp shown in Fig. 2 is made on practically the same principle as the one shown in Fig. 1, but several improvements have been introduced. The clamp is recessed at the bottom for a distance *b*, to a depth equal to *a*, so as to give a bearing only on the two extreme ends of the clamp. Even if the strap should bend somewhat, on account of the pressure of the screw, it would be certain to bear at the ends and exert the required pressure on the object being clamped. This strap is also provided with a ridge at *D*, located centrally with the hole for the screw. This insures an even bearing of the screw-head on the clamp, even if the two bearing points at each end of the clamp should vary in height, as illustrated in Fig. 3. The clamp in Fig. 1 would not bind very securely, under such circumstances, and the collar of the screw would be liable to break off, as the whole strain, when tightening the screw, would be put on one side.

A further improvement in the construction of this clamp may be had by rounding the under side of the clamping points

A, as shown in Fig. 4. When a clamp with such rounded clamping points is placed in a position like that indicated in Fig. 3, it will bind the object to be held fully as firmly as if the two clamping surfaces were in the same plane.

The hole in these straps is very often elongated, as indicated by the dotted lines in Figs. 1 and 2. This allows the strap to be pulled back far enough so as to clear the work, making it easier to insert and remove the piece to be held in the jig. In some cases, it is necessary to extend the elongated hole, as shown in Fig. 5, so that it becomes a slot, going clear through to the end of the clamp, instead of being simply an oblong hole. Aside from this difference, the clamp in Fig. 5 works on exactly the same principle as the clamps previously shown.

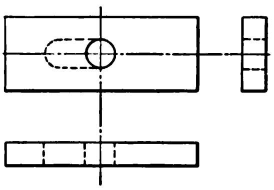


Fig. 1.

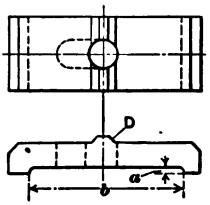


Fig. 2.

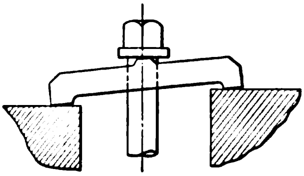


Fig. 3.

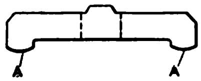


Fig. 4.

The clamps described may be given a number of different shapes to suit different conditions. Instead of having the strap or clamp bear on only two points, it is sometimes necessary to have it bear on three points, in which case it may be designed similar to the strap shown in Fig. 6. In order to get an equal pressure on all the three points, a special screw, with a half-spherical head like the one shown, may be used to advantage. The half-spherical head of this screw fits into a concave recess of the same shape in the strap. When the bearing for the screw-head is made in this manner, the hole through the clamp must have plenty of clearance for the body part of the bolt.

When designing clamps or straps of the types shown, one of the most important considerations is to provide enough metal around the holes, so that the strap will stand the pressure of the screw without breaking at the weakest place, which naturally is in a line through the center of the hole. As a rule, these straps are made of machine steel, although large clamps may sometimes be made from cast iron.

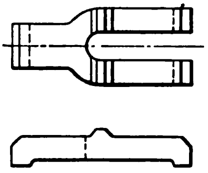


Fig. 5.

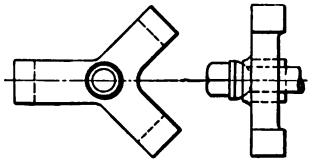


Fig. 6.

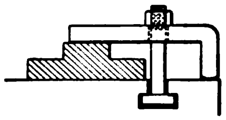


Fig. 7.

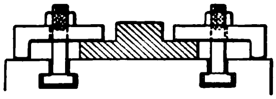


Fig. 8.

Figs. 7 and 8 show clamps bent to meet the requirements, and also indicate the application of this type of clamp, the part shown in cross-section being the work. These clamps are commonly used for clamping work in the planer and milling machine, but are also frequently used in jig and fixture design.

The screws used for clamping these straps are either standard hexagonal screws or standard collar-head screws. When it is not necessary to tighten the screws very firmly, thumb-screws are frequently used, especially on small jigs.

Sometimes the strap or clamp is arranged as shown in Fig. 9, the screw passing through it at the center and bearing upon the work, either directly, as indicated, or through the medium of a collar fitted to the end of the clamping screw, as shown in

Fig. 10. This type of clamping arrangement is commonly used for holding work in a drill jig when one screw is sufficient. The strap used in this type of arrangement can be improved upon by making it in one of the forms shown in Fig. 11. Here the ends of the straps are slotted in various ways, so as to make it easy to rapidly remove the strap when the work is to be taken out of the jig. Fig. 12 illustrates a method which is not often found in use. This type of clamp is adapted to box jigs; it has the advantage of being easily removed, which is accomplished by sliding it longitudinally. By glancing at the detailed view to the right, which shows the end of the clamping bar and its retaining grooves, the way in which it is held in place and removed will be clearly understood. Figs. 13 and 14 show clamps

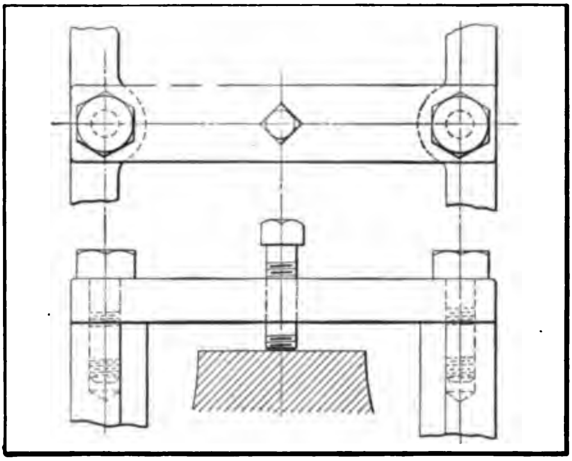


Fig. 9. Clamping Strap for Open-end Jigs

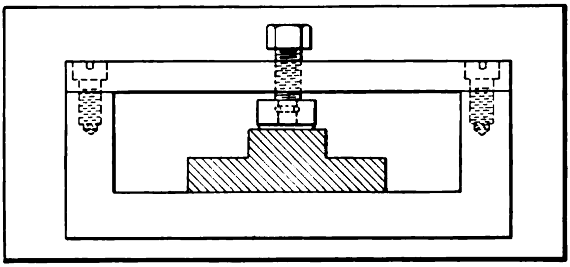


Fig. 10. Common Form of Clamps with One Binding Screw

which are very much alike, but that of Fig. 14 is simpler and more rapidly operated when the work is to be removed. When the clamp is slotted as shown in the plan view of Fig. 14, fixed studs may be used instead of the swinging bolts.

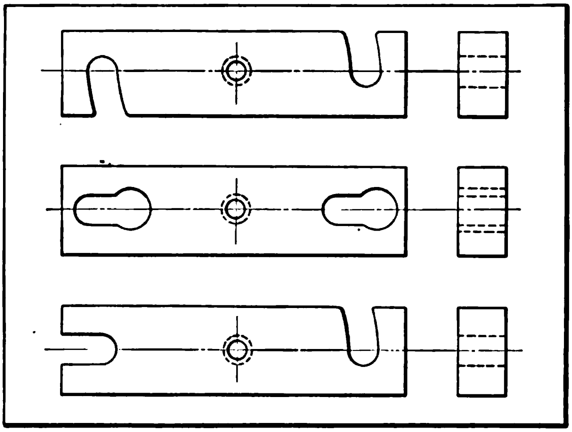


Fig. 11. Types of Clamping Straps

The type shown in Fig. 15 is often found in machine shops, on milling fixtures, drill jigs, lathe fixtures, etc. The clamp and bolts can be removed by loosening the nuts and pulling out the slip washers which allow the nuts to pass through the large holes. Fig. 16 illustrates a method which is commonly used on milling fixtures when light milling is to be done. The design of clamp shown in Fig. 17 is not frequently seen in use, as it is a method which a mechanic will not use if he can see another way out of it; but at times it is found almost impossible to use a clamp of a different type.

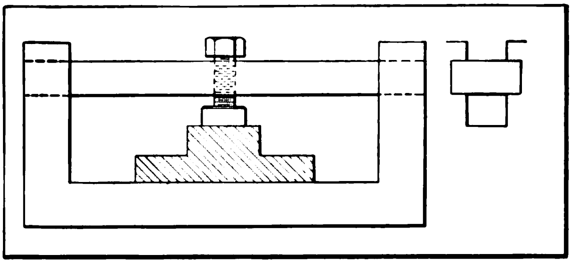


Fig. 12. Clamp Adapted to Box Jigs

A style of clamp that is somewhat similar to the one illustrated in Fig. 12 is shown in Fig. 18. In this case, however, two clamping bolts are used and the clamp is removed from the end of the jig. This is a good as well as a quick method of clamping work in open-end drill jigs. Fig. 19 illustrates the use of bolts only, for holding down work. The illustration is self-explanatory. Fig. 20 shows a good design of clamp for holding work in a milling fixture. It binds the work both horizontally and vertically and is the very best type for its purpose when it can be used.

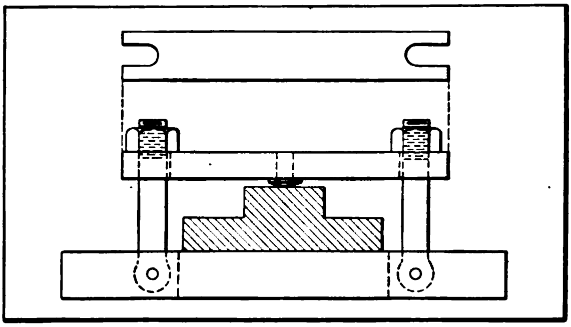


Fig. 13. Clamp with Swinging Bolts

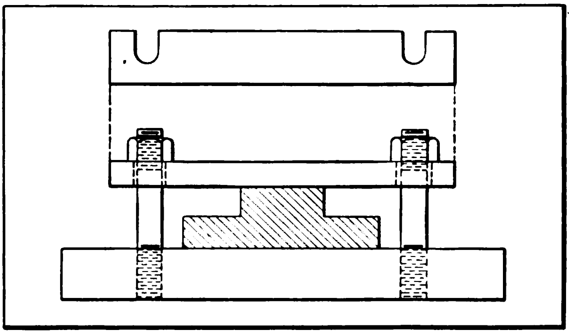
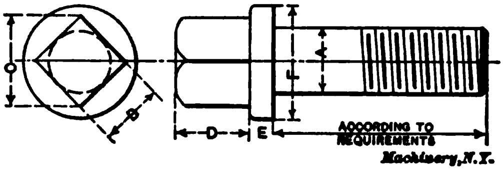


Fig. 14. Easily Removable Clamp

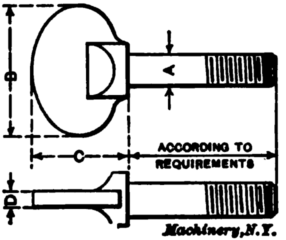
Hook-bolts. — The hook-bolt shown in Fig. 21 is better adapted for some classes of work than any other clamping device. At the same time, it is very cheap to make and easily applied. The bolt *A* passes through a hole in the jig, having a good sliding fit in this hole, and is pushed up until the hook or

Dimensions of Collar-head Screws used on Jigs



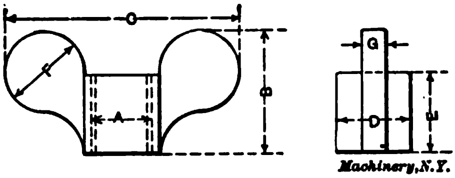
A	B	C	D	E	F	St'd No. of Threads per Inch
3/16	3/16	0.260	1/4	3/32	3/8	24
1/4	1/4	0.350	5/16	1/8	1/2	20
5/16	5/16	0.440	3/8	1/8	9/16	18
3/8	3/8	0.530	7/16	5/32	11/16	16
7/16	7/16	0.620	1/2	5/32	3/4	14
1/2	1/2	0.710	9/16	3/16	7/8	13
9/16	9/16	0.790	5/8	3/16	1	12
5/8	5/8	0.880	11/16	7/32	1 1/16	11
3/4	3/4	1.060	13/16	1/4	1 1/4	10

Dimensions of Shoulder Thumb-screws used on Jigs



A	B	C	D
3/16	9/16	1/2	3/32
1/4	1	11/16	1/8
5/16	1 1/8	3/4	5/32
3/8	1 1/4	13/16	5/32
7/16	1 1/2	15/16	3/16
1/2	1 5/8	1 1/8	3/16

Dimensions of Wing- or Thumb-nuts for Jigs



A	B	C	D	E	F	G
3/16	5/8	1 1/8	5/16	3/8	7/16	1/8
1/4	3/4	1 3/8	15/32	1/2	17/32	5/32
5/16	3/4	1 3/8	15/32	1/2	17/32	5/32
3/8	13/16	1 11/16	17/32	9/16	5/8	5/32
7/16	7/8	2	21/32	5/8	11/16	3/16
1/2	1 1/16	2 1/4	3/4	13/16	7/8	3/16

head *B* bears against the work, after which the nut is tightened. When great pressure is not required, the thumb- or wing-nut provides a satisfactory means for tightening down upon the work, and permits the hook-bolt to be applied more readily. The thumb- or wing-nut is preferable to the knurled nut, shown in Fig. 24, which sometimes is used. It is possible to get a better grip and to tighten the bolt more firmly with a wing-nut than with a knurled nut. When the work is removed from the jig, using the hook-bolt clamping device, the nut is loosened and the head or hook of the bolt is turned away from the work, thus allowing it to be taken out and another piece of work to be placed in position. The hook-bolts are invariably made of machine steel. Fig. 25 shows an application of a bent hook-bolt. Generally speaking, the type shown in Fig. 21 is better

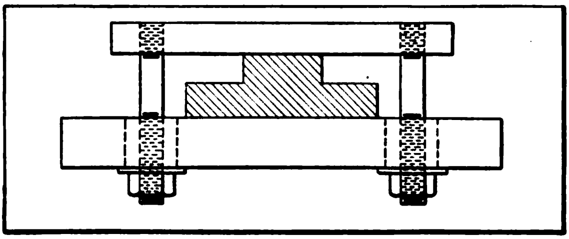


Fig. 15. Clamp with Slip Washers beneath Nuts

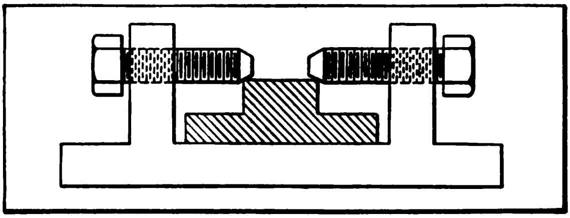


Fig. 16. Method used for Light Work

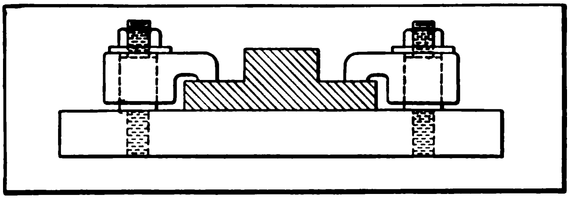


Fig. 17. Clamping Method not to be Recommended

suited to its purpose, because the bearing point on the work is closer to the bolt body.

Screw Tightening Devices. — In a box jig, or a jig where the work is entirely, or almost entirely, surrounded by the jig, the work is easily held in place by set-screws which are used whenever great clamping pressure is required, the square head allowing the use of the wrench. Sometimes screws of this kind may be tightened enough for the purpose by hand if a pin is put through the head of the screw, as shown in Figs. 22 and 23. This means is used not only when great pressure is not necessary, but also when the work is liable to spring if the screws are

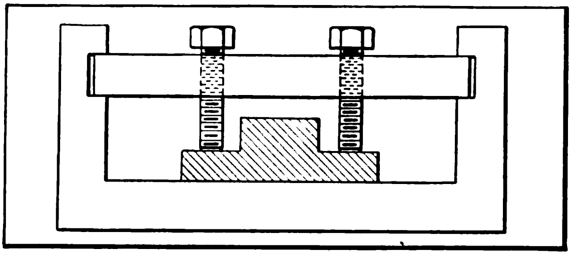


Fig. 18. Simple Clamping Method

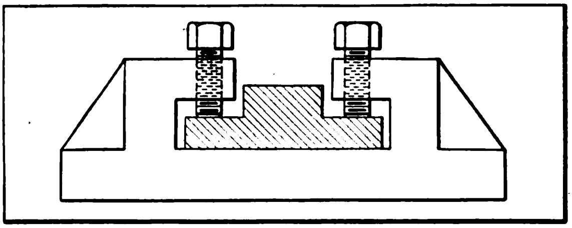


Fig. 19. Clamping by Set-screws in Open-end Jig

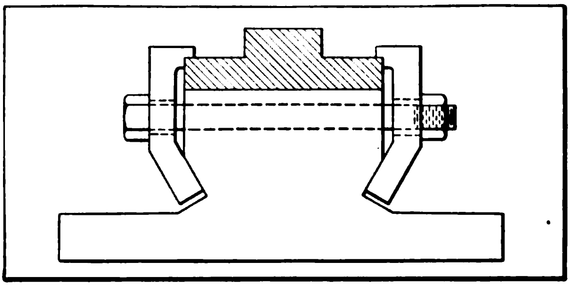


Fig. 20. Clamps that hold the Work Firmly in place

tightened too hard. In such a case, if a pin is inserted, it is obvious that the screw-head is not intended for a wrench, but that the pin is intended for getting a good grip by the hand for tightening the screw, without resorting to any additional means. Usually it is not possible to use an ordinary machine wrench on such a screw. Wing-nuts are generally most satisfactory for jigs where only a light binding pressure is required.

Wing-nuts are used on hook-bolts or swiveling eye-bolts, when a comparatively light pressure is required. The thumb-

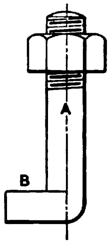


Fig. 21.

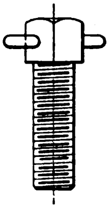


Fig. 22.

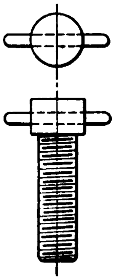


Fig. 23.

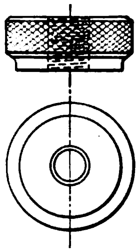


Fig. 24.

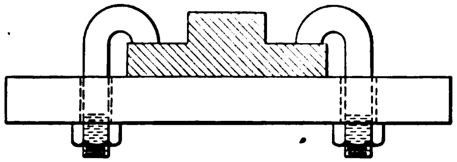


Fig. 25. Hook-bolt Method of Clamping

or wing-nut is preferable to a knurled nut, as it gives a better grip and makes it possible to tighten the bolt more firmly. The dimensions of an excellent design of handwheel for use on jigs, etc., are given in an accompanying table. These wheels have a rather long stem or hub which provides a good length of thread and brings the grip or handle far enough from the jig body to prevent the fingers or knuckles from striking it. The "star" design of handle also permits a good grip. By having the casting solid, these handwheels can be tapped out for any size thread, or a plain hole can be drilled when it is desired to attach the handles to round stock.

If screws are to be firmly tightened without the use of a wrench, the method of using a pin through the screw-head should be used only on large fixtures, where the pin is ½ inch in diameter and requires the use of both hands, an application of which is shown in Fig. 26. On smaller sizes of fixtures where the pin is about ¼ inch in diameter by 4 inches long, and must be used with one hand, the pressure is concentrated across the palm of the hand, and if the fixture is used frequently it is likely to develop a sore spot.

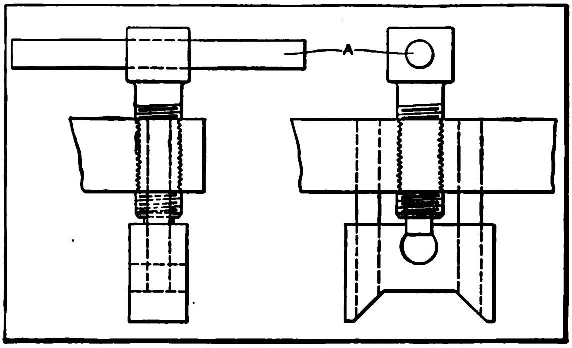


Fig. 26. Pin used as Handle for Binding Screw

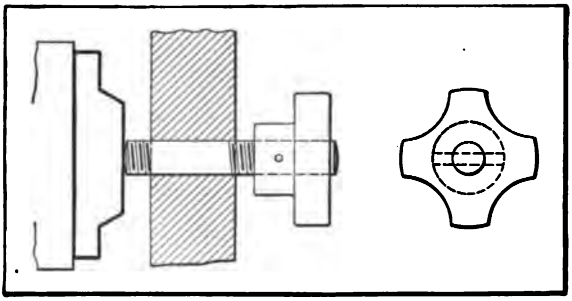
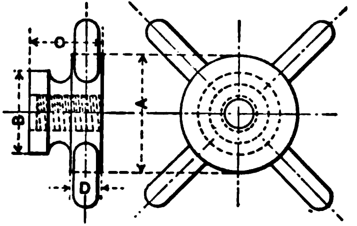


Fig. 27. Hand Knob for Binding Screw

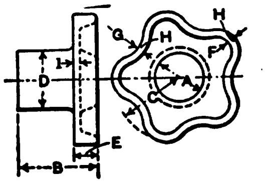
In the case of the hand knob shown in Fig. 27, however, it is evident that the pressure is distributed over the palm of the hand, and therefore the likelihood of producing a sore is much less. Tables of sizes of two different types of knobs for different classes of fixtures are given herewith.

Dimensions of Latch Nuts



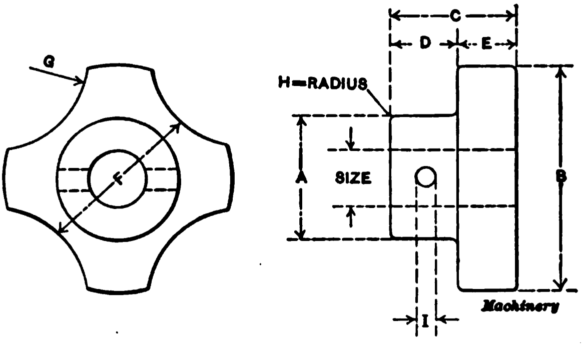
A	B	C	D
5/8	7/16	5/16	5/32
3/4	1/2	3/8	5/32
7/8	9/16	7/16	3/16
1	5/8	1/2	3/16
1 1/8	3/4	5/8	1/4
1 1/4	7/8	3/4	5/16

Star Handwheels for Jigs



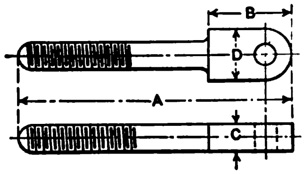
A	B	C	D	E	F	G	H	I
3/4	1 3/4	1	1	3/8	3/16	5/16	1/8	1/8
1	1 7/8	1 1/4	1 1/8	7/16	5/16	7/16	1/8	1/8
1 1/8	2	1 1/2	1 3/8	1/2	3/8	9/16	3/16	3/16
1 1/2	2 1/8	2	1 5/8	9/16	1/2	11/16	3/16	3/16
1 5/8	2 1/4	2 1/2	1 3/4	5/8	7/8	7/8	3/16	1/4

Dimensions for Cast-iron Knobs



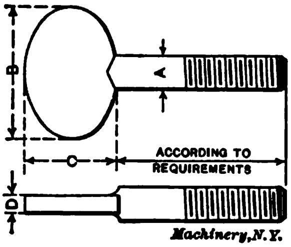
Size	5/16	3/8	1/2	9/16	5/8	3/4
A	11/16	7/8	1 1/16	1 3/16	1 1/4	1 1/2
B	1 1/4	1 5/8	2 1/8	2 3/8	2 3/4	3
C	11/16	7/8	1	1 1/16	1 1/4	1 1/4
D	3/8	1/2	5/8	5/8	3/4	3/4
E	5/16	3/8	3/8	7/16	1/2	1/2
F	7/8	1	1 3/16	1 1/2	1 1/2	1 3/4
G	1/2	9/16	5/8	3/4	7/8	1
H	1/16	3/32	3/32	1/8	1/8	1/8
I	3/32	3/32	1/8	3/16	3/16	3/16

Dimensions of Jig-screw Latches



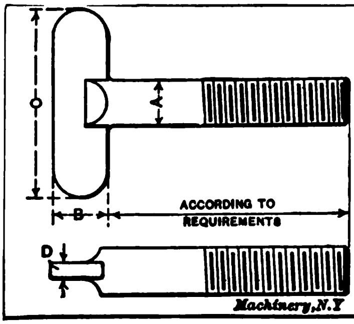
A	B	C	D
1 1/4	3/8	1/8	5/16
1 3/4	5/8	5/32	3/8
2 3/8	3/4	3/16	7/16
2 7/8	7/8	1/4	1/2
3 1/2	1	5/16	5/8
4 1/8	1 1/4	3/8	3/4

Dimensions of Regular Thumb-screws



A	B	C	D
3/16	3/4	5/8	3/32
1/4	15/16	3/4	1/8
5/16	1 1/8	7/8	5/32
3/8	1 1/4	15/16	5/32
7/16	1 1/2	1 1/16	3/16
1/2	1 5/8	1 3/16	3/16

Dimensions of Thumb-screws with Wide Grip



A	B	C	D
3/16	1/4	7/8	3/32
1/4	5/16	1	1/8
5/16	3/8	1 1/4	5/32
3/8	7/16	1 1/2	5/32
7/16	1/2	1 3/4	3/16
1/2	9/16	2	3/16
9/16	5/8	2 1/4	3/16
5/8	11/16	2 1/2	7/32

The questions naturally arise, how much pressure can a man exert with his fingers in operating a knurled-head screw, how much pressure can he develop with a screw and hand knob, and how much pressure can he exert in operating a screw with a pin through it? It is quite safe to say that for continuous operation on jigs or fixtures all that can be depended upon with a knurled-head screw is to bring the screw up to steady the work, but, with a screw and pin through it, it is not uncommon to bend the pin. With a hand knob the amount of pressure is doubtful and depends largely upon the position of the screw, which governs the grip obtainable on the knob.

Swinging Leaves. — The elementary principles involved in the swinging-leaf clamping construction are shown in their simplest form in Fig. 28. Loose leaves which swing out, in order to permit the work to be inserted and removed, are usually constructed in some manner similar to that shown in Fig. 29, in which *A* represents the leaf, being pivoted at *B* and held by a pin at *C*, which goes through the two lugs on the jig wall and passes through the leaf, thus binding the leaf and allowing the

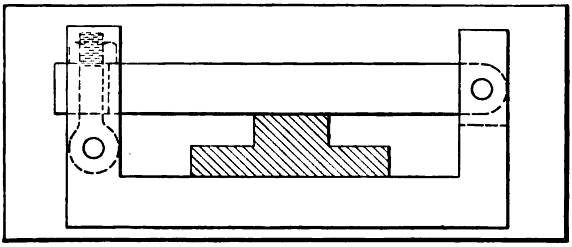


Fig. 28. Principle of Commonly used Clamping Method

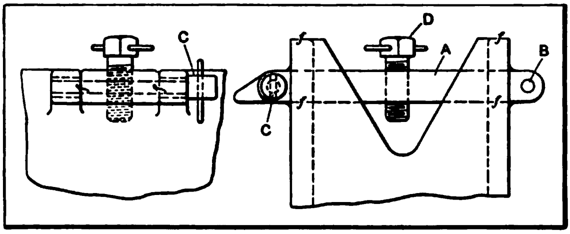


Fig. 29. Another Common Design of Jig Leaf

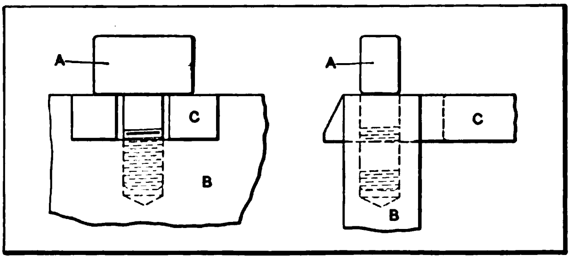


Fig. 30. Clamping Device for Drill Jig Leaf

tightening of the set-screw *D*, which bears against the work. The holes in the lugs of the castings are lined with steel bushings in order to prevent the cast-iron holes from being worn out too soon by the constant pulling out and putting in of the pin. This kind of leaf, when fitted in nicely, is rather expensive, but is used not only for binding purposes, but also for guiding purposes, making a convenient seat for the bushings. If leaves are fitted well in place, the bushings in the leaves will guide the cutting tools in a satisfactory manner.

Another method of clamping down the leaf is shown in Fig. 30, in which *A* is a thumb-screw, screwed directly into the wall *B* of the jig, and holding the leaf *C* down, as indicated. To swing the leaf out, the thumb-screw is turned back about a quarter of the turn, so that the head of the thumb-screw stands in line with the slot in the leaf, this slot being made wide and long enough to permit the leaf to clear the head of the thumb-screw. This is a very rapid way of clamping, and is frequently used. The lower side of the head of the screw will wear a long time before the head finally comes in line with the slot when binding. It can then easily be fixed for binding the leaf again when standing in a position where the head of the thumb-screw is at right angles to the slot, by turning off a portion of the head on the under side.

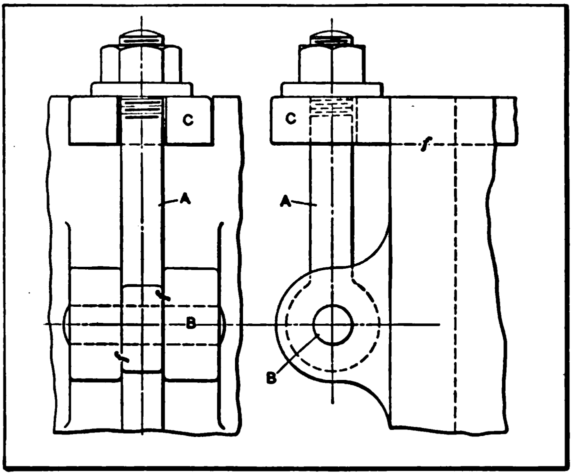


Fig. 31. Eye-bolt used for Clamping Drill Jig Leaf

The size of these thumb-screws is made according to the strain on the leaf and the size and design of the jig. No standard dimensions could be given for this kind of screw.

The hinged bolt or latch bolt, shown in Fig. 31, is also commonly used. Here *A* represents an eye-bolt, which is connected with the jig body by the pin *B*. The leaf or movable part *C* of the jig is provided with a slot in the end for the eye-bolt, this slot being a trifle wider than the diameter of the bolt. The threaded end of the eye-bolt is provided with a standard hexagon nut, a knurled-head nut or a wing-nut, according to how firmly it is necessary that the nut be tightened.

When the leaf is to be disengaged, the nut is loosened up enough to clear the point at the end of the leaf, and the bolt is swung out around the pin *B*, which is driven directly into lugs projecting out from the jig wall, a slot being provided between the two lugs, as shown, so that the eye-bolt can swing out with perfect freedom. At the opposite end, the leaves or loose parts of the jig swing around a pin the same as in Fig. 29, the detailed construction of this end being, most commonly, one of the three types shown in Fig. 32. It must be understood that to provide jigs with leaves of this character involves a great deal of work and expense, and they are used almost exclusively when one or more guide bushings can be held in the leaf.

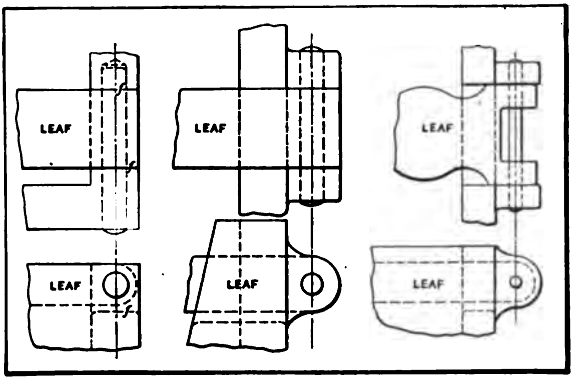


Fig. 32. Detail Designs of Hinged Leaves

Quite often drill jigs have a bushing plate in the form of a leaf which swings on a hinge out of the way so that the piece to be drilled can be put in place in the jig. This requires a locking device which can be depended upon to hold the bushing plate exactly in place while drilling. The locking device shown in Fig. 33, and also shown applied to a jig in Fig. 34, answers this purpose admirably. To open the jig so as to put in the piece to be drilled, all that is necessary to do is to push the button on the end of the lock trigger and lift the leaf up. When the piece is in place in the jig, the leaf is again pressed down into place. The pressure springs the locking device, and the trigger grips the pin shown. The part of the trigger which fits against the pin should taper slightly. This makes it hold much more tightly, and also takes up what little wear there may be on it. The device can be fitted to a great variety of jigs and fixtures. It is very simple and inexpensive to make, is quick and simple to operate, and is positive in its action.

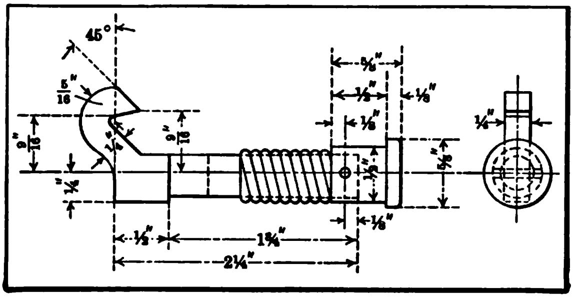


Fig. 33. A Jig Locking Trigger

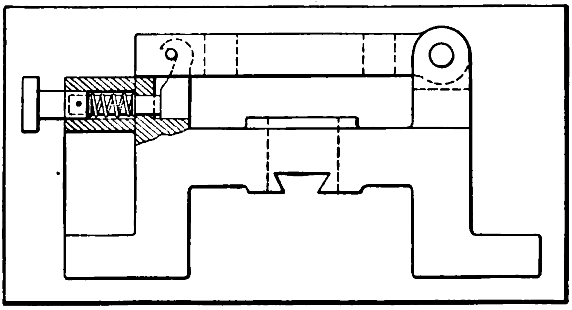


Fig. 34. Locking Device in Fig. 33 applied to Jig

A hinged jig cover may also be conveniently held in place by means of a spring latch of the form shown in Fig. 35, which is semi-automatic in its action. In this illustration, the body of the jig is shown at *A* and the hinged cover at *B*. This cover swings on the pivot *C* and drops onto the latch *D* which takes the place of the locking screw arrangement shown in Fig. 36, and which shows an application of the principle illustrated in Fig. 30. In cases where the cover is merely used to carry bushings, a latch of this kind is entirely satisfactory, although it is not recommended for use on jigs where screws for holding down the work are carried by the cover. The method of using is evident from the illustration. To swing the cover clear of the work in the jig, the latch *D* is pushed back in the direction of the arrow. After the cover has been raised, the latch springs back into place ready to catch over the top of the cover, when it is dropped back onto the jig. When the cover is dropped, the latch catches it automatically, requiring no attention from the operator.

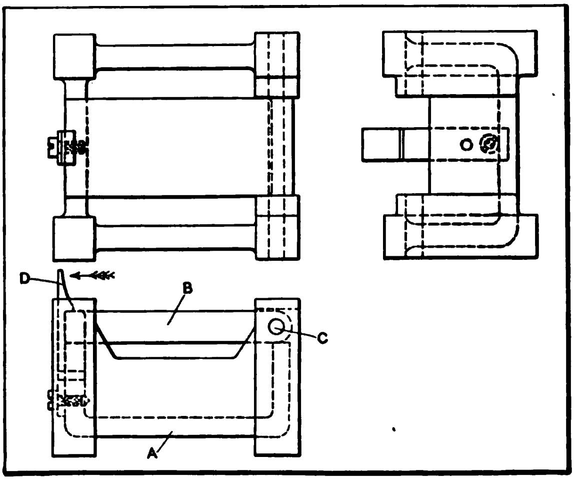


Fig. 35. Jig with Cover held by Spring Latch

A number of applications that vary in details only are shown in Figs. 37 to 40. Fig. 37 shows the style of clamp that is used in connection with box drill jigs when it is desired to support a part to be drilled on two points. As will be seen, these two bearing points are self-adjusting. The design of Fig. 38 is generally used when it is desired to support the work in two places in an open-end drill jig. Figs. 39 and 40 show types which are quite similar, but there are many cases where one type can be used to advantage and not the other. For instance, the clamp, Fig. 39, is intended for box jigs, but the type shown in Fig. 40 could not be used for such a jig, because the latter is altogether too slow. However, its advantages over Fig. 39, in case it is desired to have an open-end jig, are apparent. The relation of the first cost of a jig to the quantity of work to be done is a factor which sometimes makes a jig which is not perfect, from a purely mechanical standpoint, more desirable than one which represents better design, but greatly increased cost.

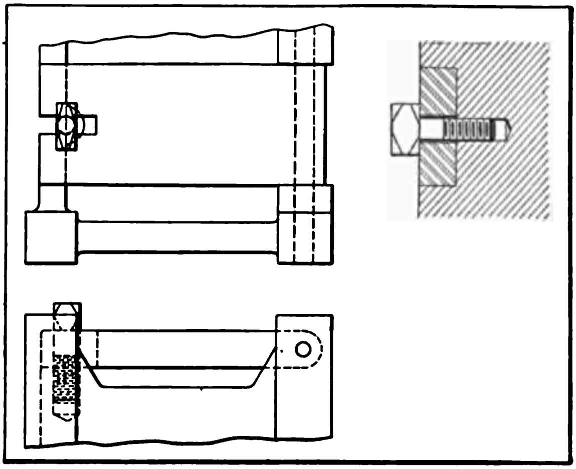


Fig. 36. Jig Cover Locked by Quarter-turn Screw

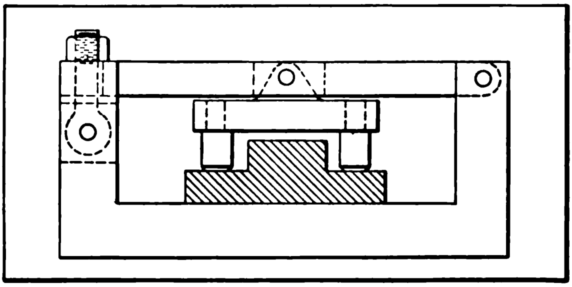


Fig. 37. Jig Cover with Two-point Self-adjusting Clamp

The ordinary jack-screw is employed quite commonly as a clamping device in drill jigs, but the objection to its use is that, not being an integral part of the jig, it is very apt to get lost. In Fig. 41 are shown two simple devices working on the same principle as the jack-screw, but having the advantage of being connected to the jig by the pin shown at *B*. At *A*, a set-screw screws directly into the end of the eye-bolt, and at *C* a long square nut is threaded on the eye-bolt. These nuts must be made of special length, and be made up especially for this purpose. The eye-bolts are fastened, as shown, directly to the wall of the jig, and the set-screw or nut is tightened against the work. The eye-bolt can be set at different angles to suit the work,

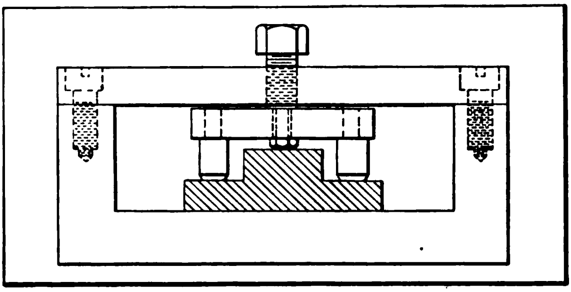


Fig. 38. Compensating Two-point Clamp

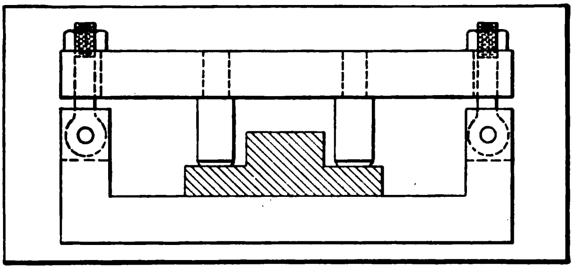


Fig. 39. Non-compensating Two-point Clamp

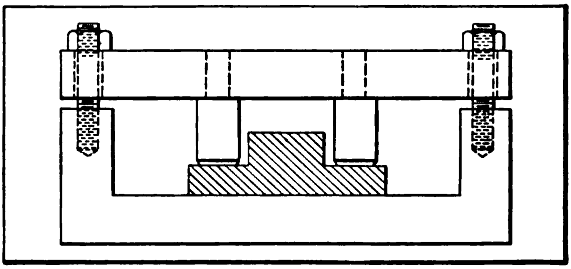


Fig. 40. Alternative Design, Similar to that in Fig. 39

thereby providing a clamping device which may be said to possess double adjustment. This device makes a very convenient clamping arrangement. It works satisfactorily and has the advantage of being easily swung out of the way.

Wedge or Taper Gib. — The principle of clamping work in the jig by means of a wedge or taper gib is shown in Fig. 42 and two applications are illustrated in Figs. 43 and 44. In Fig. 43, the work is located between the wedge *A* and the wall *B* of the jig and pressed against the wall by the wedge, which can be driven in by a hammer, or screwed in place when the jig is constructed as shown. It is preferable to have the wedge screwed in place, as it is then less likely to loosen by the constant vibrations to which it is subjected, and at the same time the wedge

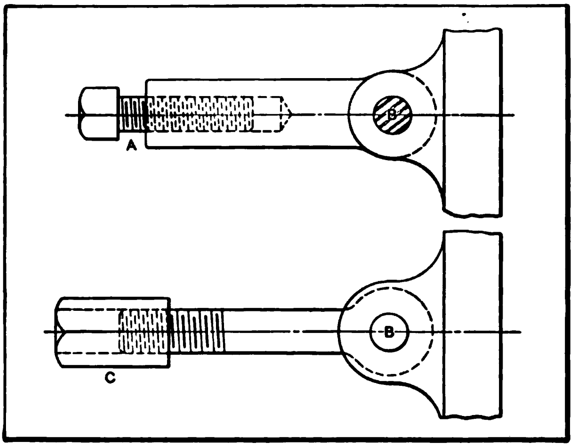


Fig. 41. Clamping Devices Working on the Jack-screw Principle

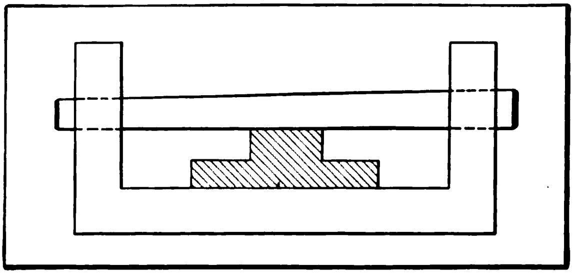


Fig. 42. Simplest Application of Wedge Clamp

is less likely to get lost, being an integral part of the jig. The ear for the screw may be placed in any direction in regard to the gib, as indicated by the dotted lines in the end view of Fig. 43. This tightening device is, in particular, adapted to work of dovetail shape, as shown in Fig. 44. In this case the wedge is made similar to the common taper gib used for taking up the wear in dovetail slides. It is sometimes of advantage to relieve the bearing surface opposite the wedge, as shown in

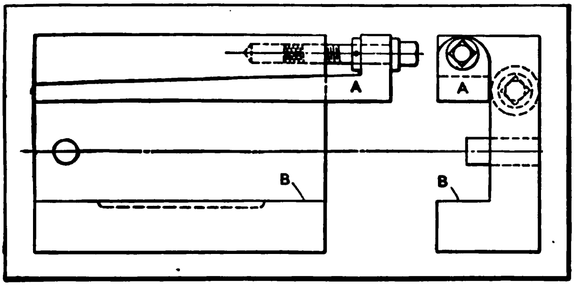


Fig. 43. Wedge or Taper Gib used for Clamping

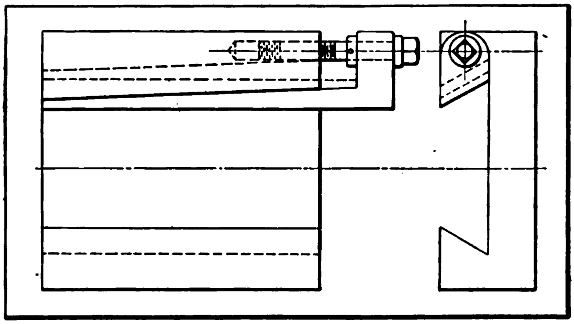


Fig. 44. Wedge for Clamping Dovetailed Work

dotted lines in Fig. 43, in order to provide two distinct bearing points, which prevent the work from rocking. The hole in the ear of the gib, through which the screw passes, must be oblong, so that when the screw is adjusted, and the gib moved in or out, there is ample allowance for the sidewise movement of the ear, due to the taper of the gib.

If it is required to get a bearing on two points of a surface that is likely to vary in its dimensions, a yoke can be used, designed on the principle of that shown in Fig. 45. In the engraving, *A* is the work to be clamped, and *B* is the yoke which fits into a slot in the center of the strap or clamp *C*. The yoke is held by a pin *D*, around which it can swivel to adjust itself to the work. It is evident that the amount of pressure at the two points *E* and *F* will be equal, or at least near enough so for all practical purposes, even though the screws at the ends of the strap may not be equally tightened. In this device the pin *D* takes the full clamping strain, and should therefore be designed strong enough, and the strap, which is weakened by the slot and the hole in the center, should be reinforced, as indicated, at this place. It is preferable to have spiral springs at each end of the strap to prevent the strap from slipping down when the work is taken out. The strap may be made either of cast iron or machine steel, the yoke being made of machine steel.

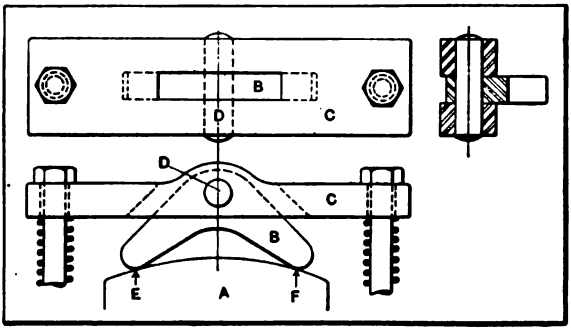


Fig. 45. Equalizing Clamp

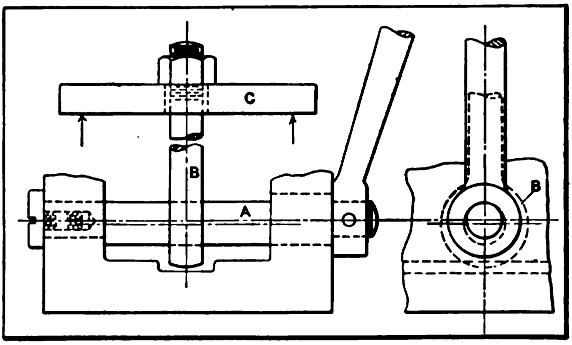


Fig. 46. Eccentric Clamping Bolt

Eccentric Clamping Arrangements. — Eccentric clamps and shafts for binding purposes are often used. In Figs. 46 and 47 are shown two applications of the principle of the eccentric shaft. In Fig. 46 the eccentric shaft *A* has a bearing at both ends, and the eye-bolt *B* is connected to it at the center and is forced down when the eccentric shaft is turned. This causes the two end points of the clamp *C* to bear on the work. This clamping arrangement has a very rapid action and gives good satisfaction. The throw of the eccentric shaft may vary from $\frac{1}{16}$ inch to about $\frac{1}{4}$ inch, depending upon the diameter of the shaft and the accuracy of the work. In cases where it is required that the clamp should bear in the center, an arrangement like the one shown in Fig. 47 may be used. Here the eccentric shaft *A* has a bearing in the center and eye-bolts *B* are connected to it at the ends. As the eccentricity is the same at both ends, the eye-bolts or connecting-rods will be pulled down evenly when the lever *C* is turned, and the strap *D* will get an even bearing on the work in the center. If the force of the clamping stress is required to be distributed equally at different points on the work, a yoke like that shown in Fig. 45 may be used in combination with the eccentric clamping device shown in Fig. 47.

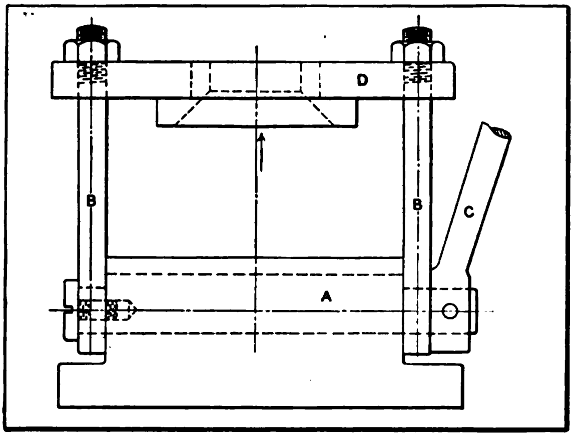
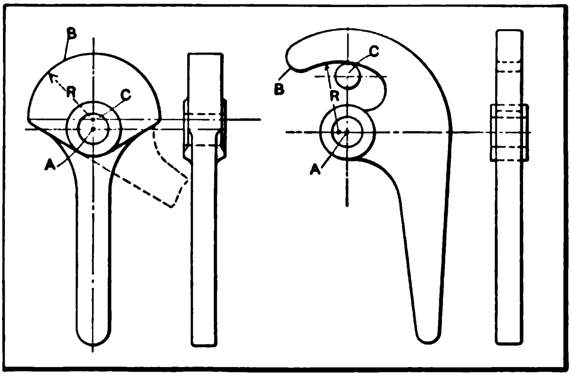


Fig. 47. Another Example of Eccentric Clamping Bolt

When it is essential that strap *D* should also be used for locating purposes, necessary guides must be provided for the strap, so as to hold it in the required position. These guiding arrangements may consist of rigid rods, ground and fitted into drilled and reamed holes in the strap, or square bars held firmly in the jig, and fitted into square slots at the ends of the strap. The bars may also be round, and the slots at the ends of the strap half round, the principle in all cases remaining the same; but the more rigid the guiding arrangement is, the more may the accuracy of the locating be depended upon.

The ordinary eccentric lever works on the same principle as the eccentric rods just described. There are a great variety of eccentric clamping devices, but they are not as commonly used in present-day jig design as they were a few years ago. The eccentric clamping levers, however, provide good and rapid clamping action. In Fig. 48 is shown one especially intended for clamping finished work. It is not advisable to use this kind of lever on rough castings, for the reason that the latter may vary so much that the cam or eccentric would require too great a throw for rigid clamping to suit the rough castings. The extreme throw of the eccentric lever should, in general, not exceed one-sixth of the length of the radius of the eccentric arc, if the rise takes place during one-quarter of a complete turn of the lever. This would give an extreme throw of, say, $\frac{1}{4}$ inch for a lever having $1\frac{1}{2}$ inch radius of the cam or eccentric. It is plain that as the eccentric cam swivels about the center *A*,



Figs. 48 and 49. Cams or Eccentrics used for Clamping

the lever being connected to the jig with a stud or pin, the face *B* of the cam, which is struck with the radius *R* from the center *C*, recedes or approaches the side of the work, thereby releasing it from, or clamping it against, the bottom or wall of the jig. The lever for the eccentric may be placed in any direction, as indicated by the full and dotted lines in Fig. 48. In Fig. 49 is shown another eccentric lever, which is used frequently on small work for holding down straps or leaves, or for pulling together two sliding pieces, or one sliding and one stationary part, which in their turn hold the work. These sliding pieces may be V-blocks or some kind of jaws. The cam lever is attached to the jig body, the leaf, or the jaw, by a pin through hole *A*. The hook *B* engages the stud or pin *C* which is fastened in the opposite jaw or part, which is to be clamped to the part into which the pin through hole *A* is fastened. The variety of design of eccentric cam levers is so great that it is impossible to show more than the principles, but the examples shown

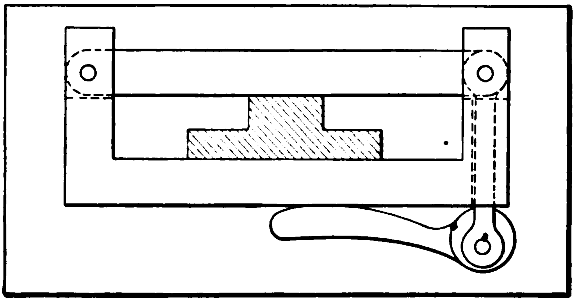


Fig. 50. Application of Clamping Cam

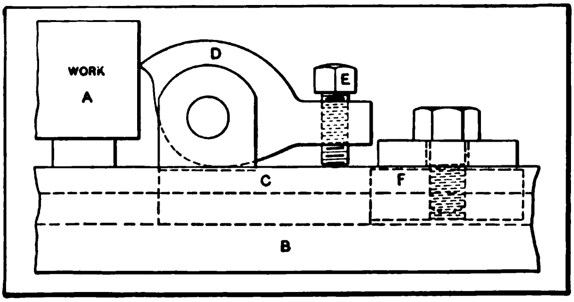


Fig. 51. The "Gripping Dog" Method of Clamping

embody the underlying action of all the different designs. An elementary application is shown in Fig. 50.

Irregular shaped castings which must be machined often present no apparently good means of holding by ordinary gripping appliances for drilling, shaping, or milling. In such cases a gripping dog, as illustrated in detail in Fig. 51, may be used. The base block *C* of the dog is slotted to receive jaw *D*, which is fulcrumed on a cross-pin. In the tail of the dog is threaded a set-screw *E*, and by turning in this set-screw the jaw is caused to "bite" inward and downward at the same time, firmly gripping the casting and forcing it down on the table. A backstop *F* is bolted behind each dog, so that there is no chance for slipping away from the work.

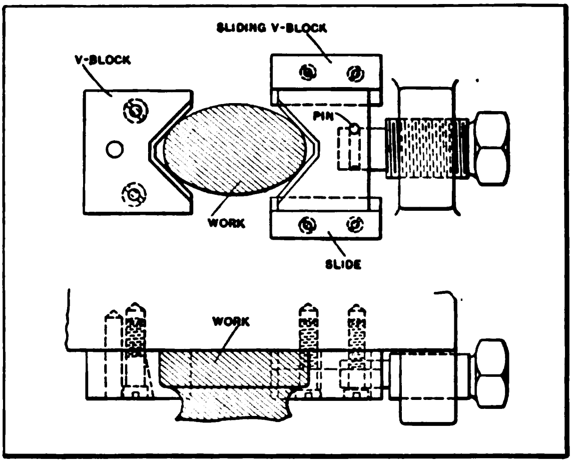


Fig. 52. Work Held by V-clamps

Applications to Jig Design. — The preceding description and illustrations indicate the principles embodied in jig clamping devices. The following typical illustrations show a number of applications that are merely modifications of the various methods already reviewed. Most of the devices described may be quickly operated, the purpose being to show a collection of efficient designs that will hold the work securely. They possess the further advantage of being relatively simple, so that the jigs can be made at a moderate cost in all cases where there are a sufficient number of pieces to be machined to warrant making a good tool.

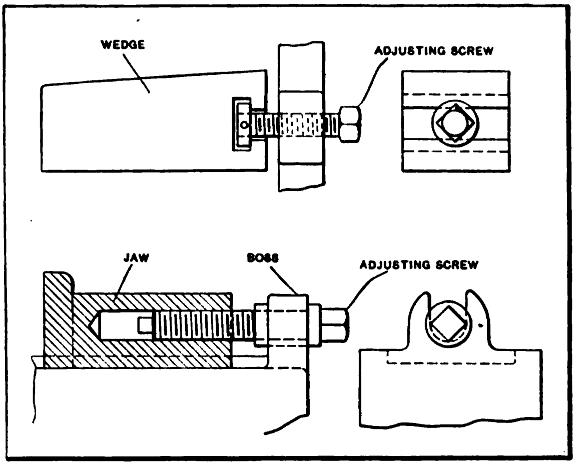


Fig. 53. Sliding Clamps

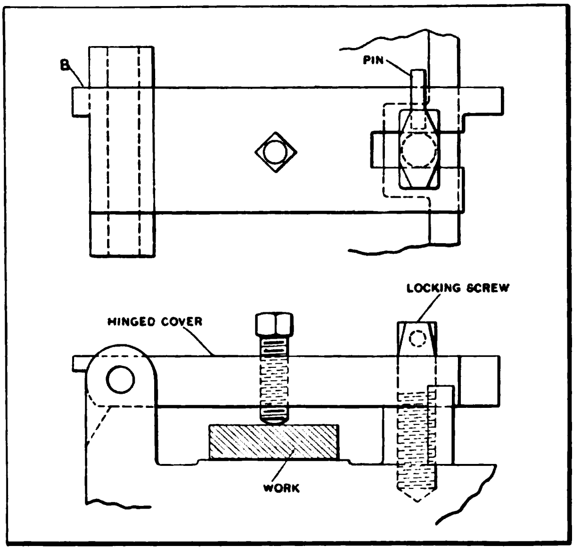


Fig. 54. Hinged Cover with Locking and Clamp Screw

A method of holding a piece of work with an oval-shaped flange is shown in Fig. 52. This piece is held between V-blocks, one of which is stationary while the other is moved by a screw.

A pilot on the end of the adjusting screw enters a hole in the V-block, the two members being held together by a pin which fits in a groove in the pilot. The movable V-block is held to the body of the jig by two steel straps. Fig. 53 illustrates, in the upper view, another method of attaching a screw to a sliding clamp member. In this case, the sliding piece is used for forcing the work down into place. This screw runs in a tapped hole in a stationary part of the fixture, while the collar at the end of the screw fits into the movable wedge to push it forward or draw it back. The lower view shows a movable clamp member that has a tapped hole to receive the adjusting screw. Here two collars on the screw are located at each side of a boss on the fixture and the adjustment is obtained by the screw turning in the tapped hole.

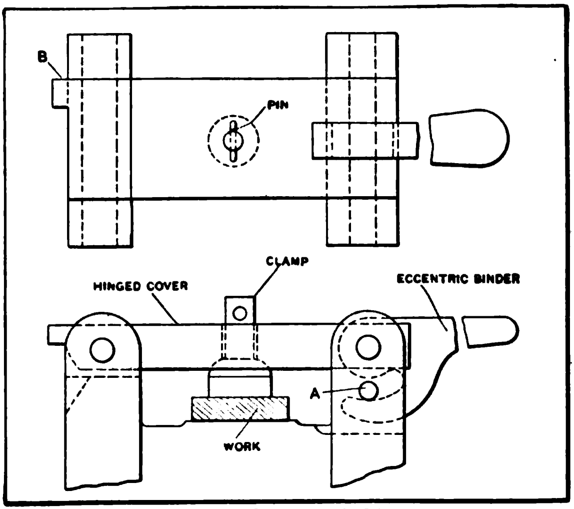


Fig. 55. Hinged Cover with Floating Stud

Two examples of hinged covers are shown in Figs. 54 and 55. The cover shown in Fig. 54 (same principle as in Figs. 30 and 36) is held in place by a locking screw, while the work is secured by a set-screw carried by the cover. The hinged cover illustrated in Fig. 55 is provided with a floating stud that secures the work, the cover which carries the stud being held in place by an eccentric binder with a hook which slides under the pin *A*.

This provides a very quick-acting jig. The lug *B* at the opposite end of the cover prevents it from swinging back too far and breaking the hinge.

Fig. 56 shows the application of a bell-mouthed bushing, which is screwed down onto the hub of a lever, thereby locating the work and at the same time providing a guide for the drill which is to operate upon it. The objection to this type of bushing is that it requires an extra long drill, and if made with two sizes of holes, as shown, particular care will have to be taken in using small drills, to prevent breaking a number of them.

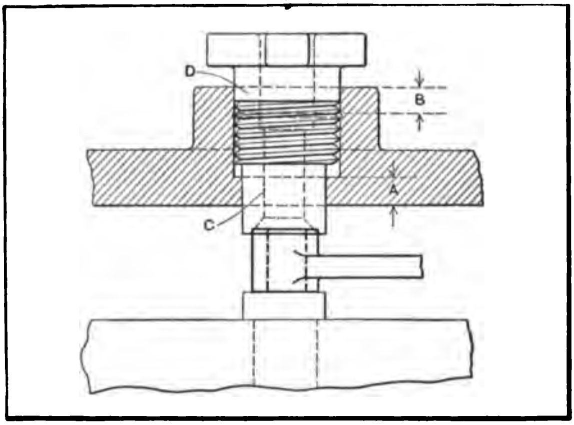


Fig. 56. Bell-mouthed Screw Bushing

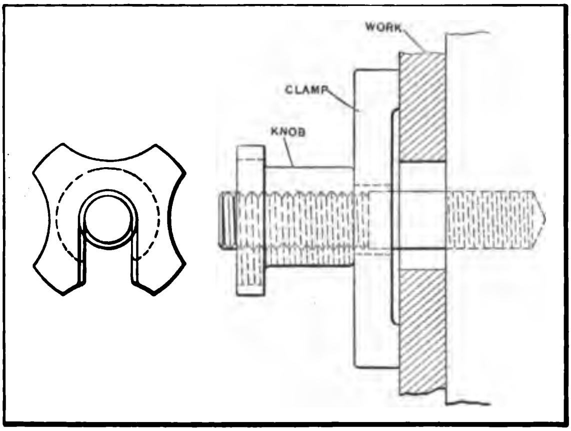


Fig. 57. Slip-on Knob for Clamping

Another objectionable feature of this clamping device is that chips work into the threads and prevent turning the bushing easily which also shortens the life of the thread. This difficulty can be overcome, however, by not tapping the hole all of the way through, as indicated at *A*; by counterboring the hole at the top marked *B*; and then grinding the pilot *C* and shoulder *D* on the bushing to a snug running fit. The bushing is then held true and chips are excluded from the thread. The average tool designer, nevertheless, avoids screw bushings whenever possible, but such bushings are frequently selected after careful consideration because of their neat appearance and effective operation.

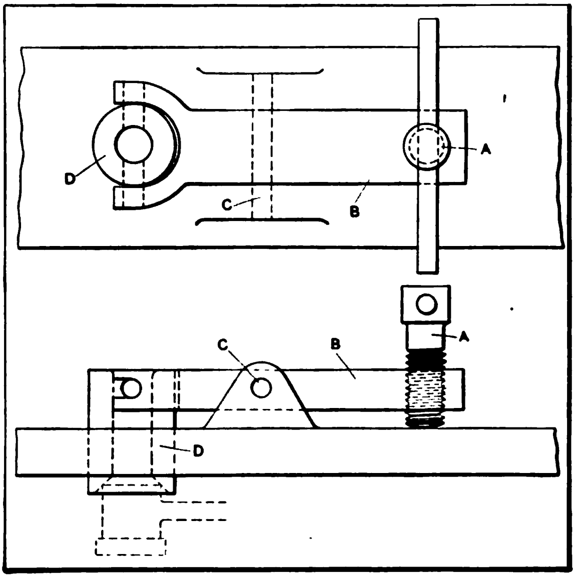


Fig. 58. An Improvement on the Screw Bushing

Fig. 58 shows a clamping device which, although a little more expensive than a screw bushing, would probably pay for itself in saving the breaking of drills, as the bushing on this jig can be made shorter and with a one-size hole. The screw *A* swings the lever *B* about pin *C* and pushes down the bushing *D* which is a slip fit in the body of the jig.

A rather unusual method of clamping is illustrated in Fig. 57, where it will be seen that the hand knob has the thread milled out to the edge to give a "slip over and twist" motion for clamping the work. Practically the same idea is illustrated in Fig. 59, except that a wrench handle is provided in this case to facilitate tightening. Both of these arrangements enable work to

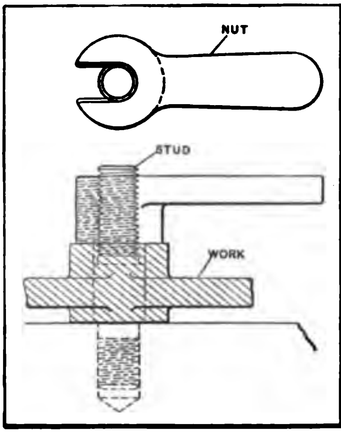


Fig. 59.

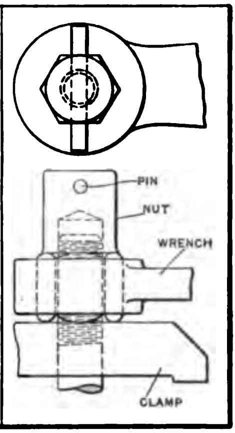


Fig. 60.

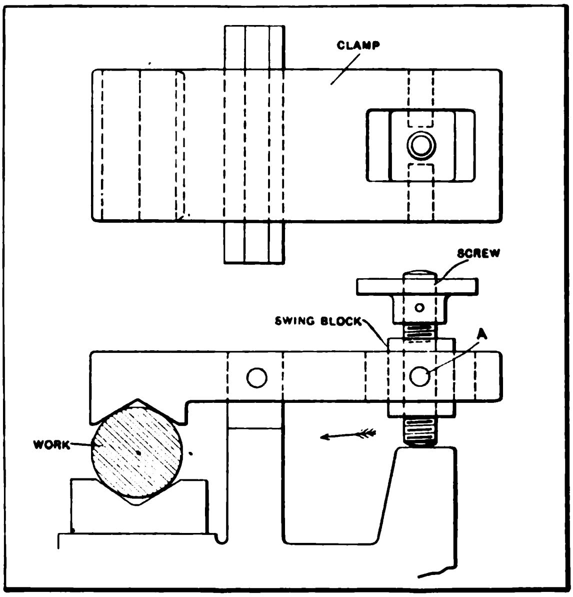


Fig. 61. Binding Screw Pivoted in Clamp

be tightened in the fixture with great rapidity. Fig. 60 shows a special nut for a box wrench, the purpose of which is to permit lifting the wrench off the "hex," and moving it back for a new grip. The round part of the nut serves to keep the wrench in place to be slipped back onto the hexagon nut, while the pin at the top of the nut makes the wrench an integral part of the fixture, so that it cannot get lost.

Two unusual examples of jig and fixture design are illustrated in Figs. 61 and 62. The distance that the clamp had to be raised in removing the work from between the V's of these fixtures made it desirable to provide some method of releasing the clamp more quickly than by turning the screw back through the necessary distance. The way in which this was accomplished is clearly shown in the illustrations, and will be seen to consist of loosening the screw and then swinging the block which carries the screw on the pivot *A*, the direction being indicated by the arrow. This moves the screw off its bearing on

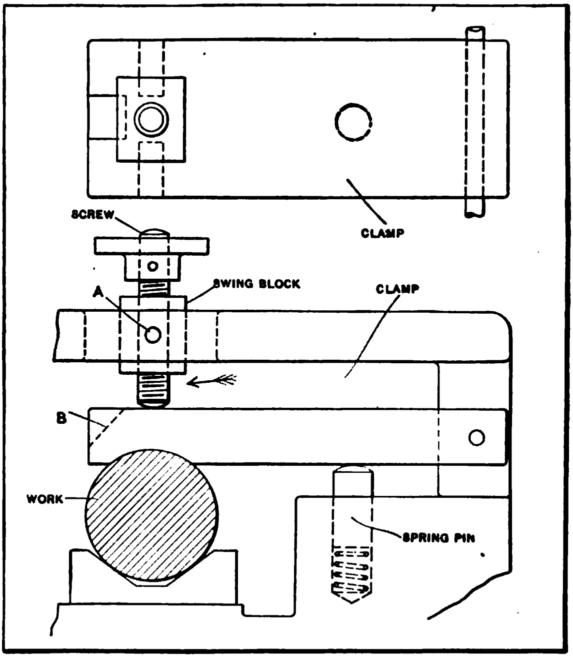


Fig. 62. Quick-releasing Clamping Arrangement

the casting in the case of the jig shown in Fig. 61, while in Fig. 62 the binding screw is removed from the clamp. The clamp shown in Fig. 62 has been cut away at *B* to permit the point of the screw to clear it; a spring-pin holds the clamp against the screw at all times.

Fig. 63 shows a hinged cover with the clamp attached to it. This is a convenient arrangement to remember when considering the design of jigs and fixtures. The clamp and cover are held by the same pin and both parts are swung out of the way at the same time by means of the corner of the clamp, which catches on the hinged cover at *B*. The design is such that the fixture has sufficient clamping range when the cover is held in place by the screw *C*. The clamping is effected by means of the screw in the cover which forces the clamp down on the work. Fig. 64 shows a clamp beveled at the end to pull the work down flush and push it into the V at the same time. The clamp is tightened by a screw and a spring forces it open when

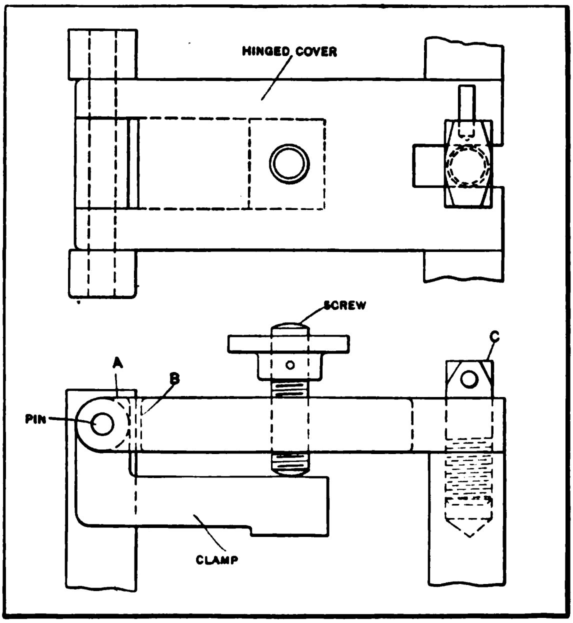


Fig. 63. Hinged Cover with Attached Clamp

the screw is loosened. This type is often used when it is desirable to keep the clamp out of the way of the cutter.

Two examples of the use that can be made of cams are shown in Figs. 65 and 66. The device shown in Fig. 65 is simply an eccentric stud operated by a handle. This device pushes the clamp against the work; a hole is drilled in the clamp to slide

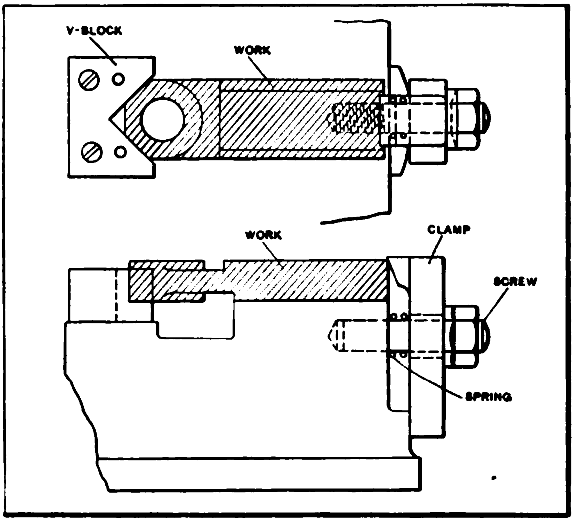


Fig. 64. V-block Clamp

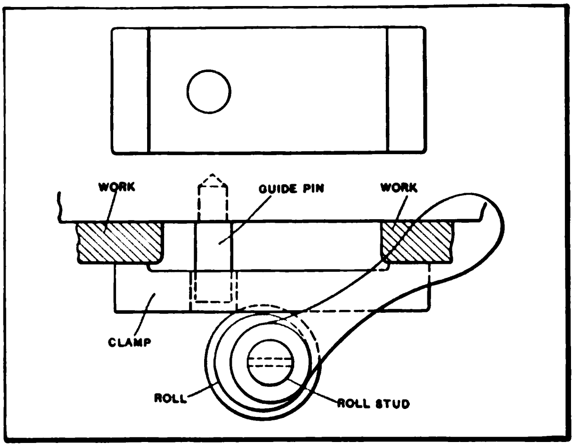


Fig. 65. Cam Clamping Device

over the guide pin mounted in the frame of the jig. Fig. 66 shows a cam for operating a sliding V, the method being evident from the illustration. Another form of quick-acting clamp is shown in Fig. 67. This device consists of a bar that is hinged on a stud at one end and has a slot cut in the opposite end to slip under a second stud. The screw that clamps the work also serves to secure the clamp in place.

A simple form of gang milling fixture is shown in Fig. 68, where the different pieces are clamped by separate screws held in a bar that can be swung out of the way to enable the work to be removed from the jig. This also makes it possible to brush the chips out at the side of the jig.

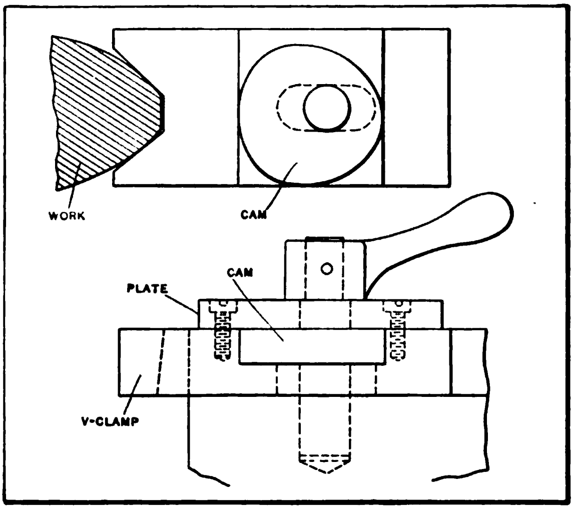


Fig. 66. Another Application of a Cam Clamping Device

In Fig. 69 is shown a clamping device that has been found useful on large work. It consists of four arms *A* with the ends bent to a right angle and knurled so as to hold the work firmly in place. These arms are pivoted on the stud *B* and their action is guided by the blocks *C*. The spring handle *E* is pinned to the shank of the stud, and the upper edge of the handle is beveled to fit the rack *D*, which is fastened to the side of the base. By turning the handle in the direction indicated by the arrow the work is securely clamped and, if necessary, ordinary straps may be added for holding the work.

When making tools for thin castings of odd shapes, it is often desirable to use an adjustable clamping device that can be easily moved out of the way when reloading the fixture. Such a floating clamp is shown in Fig. 70, where the piece of work to be drilled was properly located and clamped, with the exception of one arm *E*, for which no ordinary clamp could be used. By pushing the support *A* down against the work and

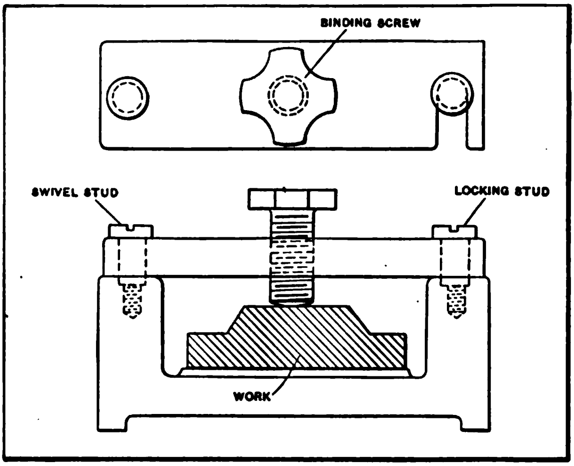


Fig. 67. Quick-acting Clamp of Simple Design

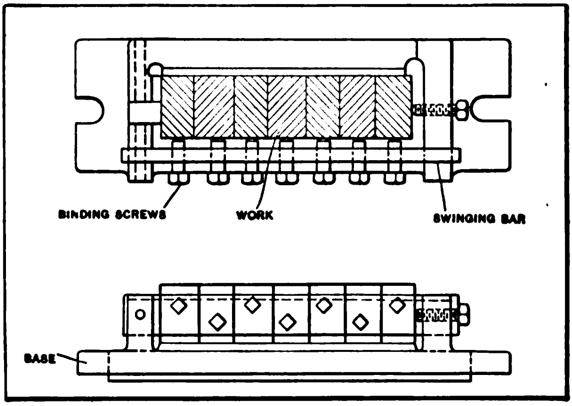


Fig. 68. Simple Form of Gang Milling Fixture

clamping the strap *B*, the work is held tight without springing it; and by tightening the nut *C* the clamp is held in place by the bunter and the work is securely supported. When reloading the fixture, the clamp is brought out of the way by means of the handle *D*.

In Fig. 71 is shown a small clamping device used when drilling the rivet holes through the beading *A* and the plate *B*. The steel bracket *C* is fastened by screws to the side of the fixture. The front face of the clamp bracket is used as a stop for the plate and the beading, and the clamp *D* with a small hole drilled in one end is fitted loosely in the milled slot in the bracket. The set-screw is located a little higher than the hole in the clamp and by a few turns of the screw the clamp is brought down against the work and forces the beading up against the stop ready to be drilled.

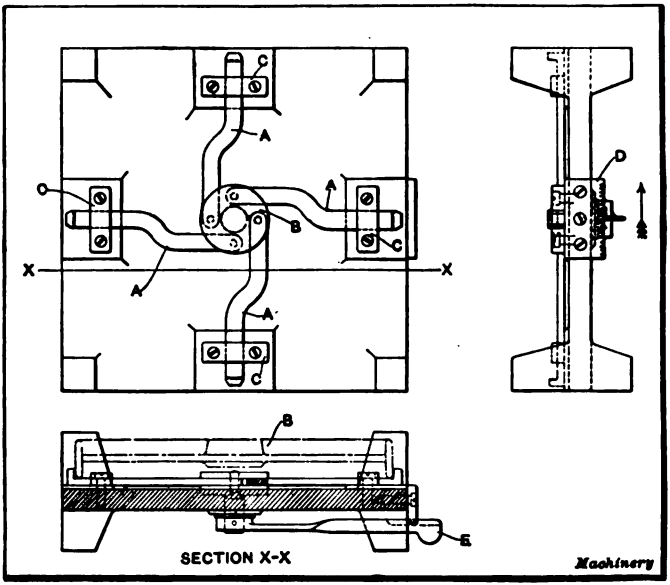


Fig. 69. Clamping Device for Holding Large Work

Spring bunters are often used in designing fixtures where adjustable supports are necessary, and the form of bunter shown in Fig. 72 has proved very efficient. The bunter *A* and the binder *B* fit freely in the holes in the casting. The bunter is

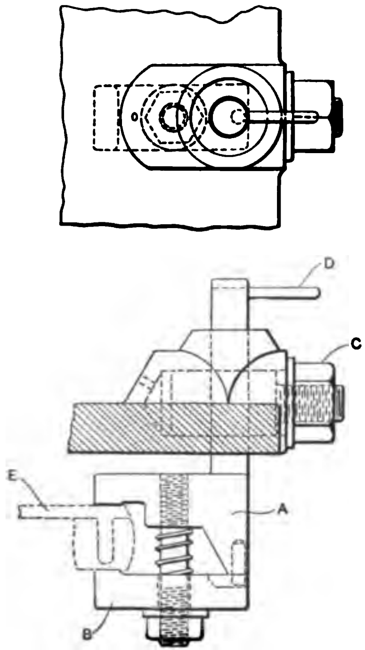


Fig. 70. Auxiliary Clamp used for Holding Odd-shaped Castings

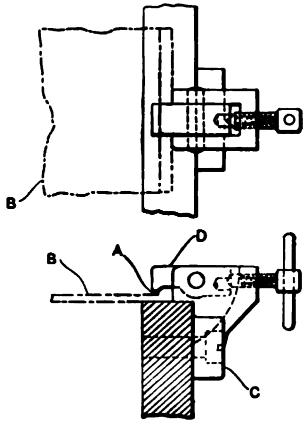
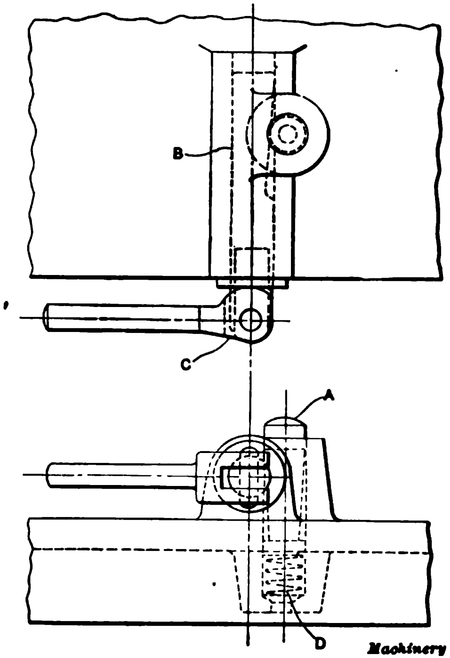


Fig. 71. Special Clamping Device for Drilling Rivet Holes



Machinery

Fig. 72. Adjustable Support used for Holding Work in a Jig

slightly tapered and a tapered flat is milled on one side of the binder. When the fixture is loaded the spring *D* forces the bunter up against the work, and by means of the cam *C* the binder is pulled outward and holds the bunter firmly in place. The double taper on both bunter and binder makes it impossible to press the bunter downward away from the work.

Conclusion. — When designing clamping devices, as few operating screws or handles should be used as will accomplish the desired result, for it takes considerable time to turn a screw one or two revolutions four or five thousand times a day, which is an average number of operations for many jigs. Making the screw with a double or triple thread is sometimes done to advantage in decreasing the number of turns necessary to release the piece. Jig lids should be hung on taper pins in order that wear in the hinge may be compensated for and the resulting inaccuracy due to the lost motion in the hinge prevented. The included angle of taper on hinge pins should be only one or two degrees and the pins should be spirally grooved to within ⅜ inch of each end, in order to hold oil for lubricating the hinge after the pin is driven in. The hinge pin should be a tight fit in the central portion of the hinge, which is usually the jig body, and a bearing fit in the ears of the lid. In this manner the greatest wearing surface possible is obtained.

All clamping screws and similar parts should be long enough and so located as to be conveniently taken hold of to operate, and of sufficient size to prevent hurting the operator's hands on account of the pressure necessary to manipulate them. The screws should be located so that they will resist the tilting action of the block, and the dowel pins should be fairly close to the screws and of liberal dimensions in order to resist the shearing strains to which they will be subjected. When clamping or locating the work in the jig, it is essential to have the clamping pressure exerted in a direct line against some solid point of support to prevent the tilting tendency, and the thrust should also come on such a point of the work that it will be resisted by solid metal, as the pressure of a screw is frequently underestimated by both the designer and the operator of the jig, with the result that the work will frequently be sprung by the clamping device and drilled in this position, which would naturally spoil the accuracy of the location of the hole after the work was released from the jig and had expanded back to its normal shape.

It should be further borne in mind when clamping rough castings in a fixture, that they can be supported only on three points, and adjustable stops should be placed on the fourth point of the support and also under any weak portions of the piece through which holes are to be drilled or machining operations are to be performed, in order to resist the springing action of the cutter. Posts in which clamping and locating screws operate should be of liberal proportions and should not project above the fixture body any further than is necessary in order to keep down the tilting action to a minimum; and all handles for clamping devices should be so located that they will not be awkward to operate.

CHAPTER XI

DESIGN OF OPEN DRILL JIGS

To give any rational rules or methods for the design of drill jigs would be almost impossible, as almost every jig must be designed in a somewhat different way from every other jig, to suit and conform to the requirements of the work. All that can be done is to lay down the principles. The main principles for jigs as well as fixtures were treated at length in Chapter VII. It is proposed in the present chapter to dwell more in detail on the carrying out of the actual work of designing jigs.

Jig Drawings. — Before making any attempt to put the layout of the jig on paper, the designer should carefully consider what the jig will be required to do, the limits of accuracy, etc., and to form, in his imagination, a certain idea of the kind of a jig that would be suitable for the purpose. In doing so, if a model or sample of the work to be made is at hand, it will be found to be a great help to study the actual model. If the drawing, as is most often the case, is the only thing that is at hand, then the outline of the work should be drawn in red (or other colored) ink on the drawing paper, on which the jig is subsequently to be laid out, and the jig built up, so to speak, around this outline. The designing of the jig will be greatly simplified by doing this, as the relation between the work and the jig will always be plainly before the designer, and it will be more easily decided where the locating points and clamping arrangements may be properly placed. When drawing and projecting the different views of the jig on the paper, the red outline of the work will not in any way interfere, and when the jig is made from the drawing, the red lines are simply ignored, except to the extent to which the outline of the pieces may help the toolmaker to understand the drawing and the purpose of certain locating points and clamping devices.

If possible, the jig should be drawn full size, as it is a great deal easier to obtain the correct proportions when so doing. Of course, in many cases, it will be impossible to draw the jigs full size. In such cases the only thing to do is to draw them to the largest possible regular scale. Every jig draftsman should be supplied with a set of blueprints containing dimensions of standard screws, bolts, nuts, thumb-screws, washers, wing-nuts, sliding points, drills, counterbores, reamers, bushings, etc.; in short, with blueprints giving dimensions of all parts that are used in the construction of jigs, and which are, or can be, standardized. It should be required of every designer and draftsman that he use these standards to the largest possible extent, so as to bring the cost of jigs down to as low a figure as possible.

It is highly desirable, for the obtaining of best results, that, before starting on the drawing, the draftsman who is to lay out the jig should consult the foreman who is actually going to use the jig. Oftentimes this man will be able to supply the best idea for the making of the jig or tool. The combined experience of the draftsman and the foreman will generally produce a much better tool than could either of them alone.

As a jig drawing, in most cases, is only used once, or at most only a very few times, it is not advisable to make a tracing or blueprint from the drawing, but, as a rule, the pencil drawing itself may be used to advantage. If, however, it is given out in the shop directly as it comes from the drawing-board, it is likely to become soiled, so that, after a while, it would be impossible to make out the meaning of the views shown on it. For this reason jig drawings should be made on heavy paper, preferably of brown color, which is not as quickly soiled as white paper; and in order to prevent the drawing from being torn, it should be mounted on strawboard, and held down along the edges by thin wooden strips, nailed to the board. It is also desirable to cover the drawings with a thin coat of shellac before they are sent out into the shop. When this is done, dirt and black spots may be washed off directly; and the shellac itself may be washed off by wood alcohol, when the drawing is returned to the drafting-room. The drawing, after having been cleaned, is then detached from the strawboard, which may be used over and over again. The drawing is, of course, filed away according to the drafting-room system. The most advantageous sizes for jig drawings for from medium to heavy work are about as follows:

1. Full size sheet, 40 × 27½ inches.
2. Half size sheet, 27½ × 20 inches.
3. Quarter size sheet, 20 × 13¾ inches.
4. Eighth size sheet, 13¾ × 10 inches.

Of course, these sizes will vary in different shops, and in many cases, particularly when the tool-designing department and the regular drafting-room are combined as one drafting department, the jig drawings should be of the same regular sizes as the ordinary machine drawings.

It is common practice in a great many shops to make no detailed drawings of jigs, but simply to draw a sufficient number of views and sections, and to dimension the different parts directly on the assembly drawings. In cases where the jig drawings are complicated, and where they are covered with a large number of dimensions which make it hard to read the drawing and to see the outlines of the jig body itself, it has proved a great help to trace the outlines of the jig body, and of such portions as are made of cast iron, on tracing paper, omitting all loose parts, and simply putting on the necessary dimensions for making the patterns. A blueprint is then made from this paper tracing, and is sent to the patternmaker, who will find the drawing less of a puzzle, and who will need to spend far less time to understand how the pattern actually looks. It is, however, good policy to detail jig drawings completely, the same as other machine details.

When jigs are made for pieces of work which require a great many operations to be carried out with the same jig, and where a great number of different bushings, different sizes of drills, reamers, counterbores, etc., are used, a special operation sheet should be provided, which should be delivered to the man using the jig, together with the jig itself. This enables him to use the jig to best advantage. On this sheet should be marked the order in which the various operations are to be performed and the

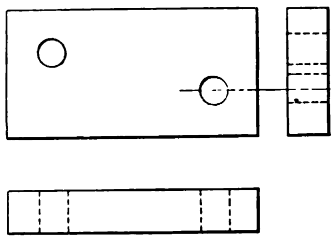


Fig. 1.

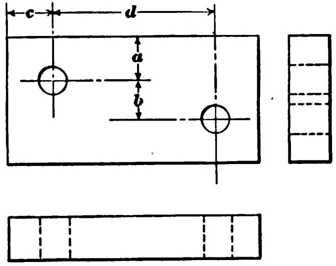


Fig. 2.

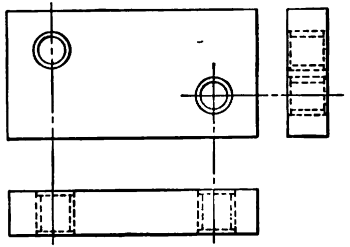


Fig. 3.

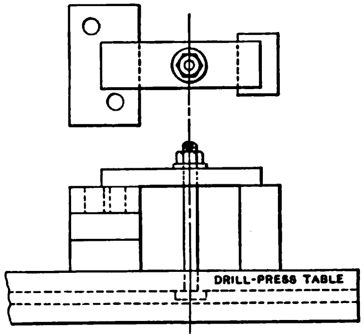


Fig. 4.

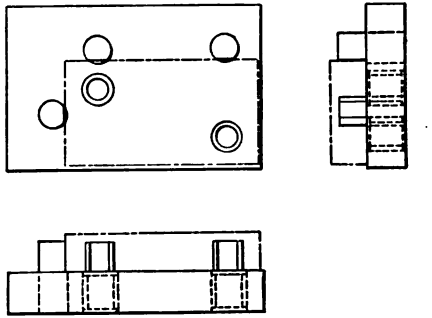


Fig. 5.

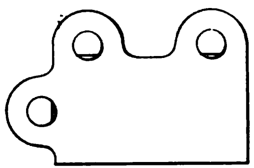


Fig. 6.

tools and bushings which are to be used. The bushings should be numbered or marked in some way so as to facilitate the selection of the correct bushing for the particular tool with which it is used. If this system is put in force and used for simpler classes of jigs also, the operator will need few or no instructions from the foreman, outside of this operation sheet.

Designing Open Jigs. — The present chapter will be devoted to explaining and illustrating the application of the principles previously outlined, to the simplest and most common design of drill jig — the open jig. Assume that the drill jig is to be designed for a piece of work, as shown in Fig. 1. Consideration must first be given to the size of the piece, to the finish given to the piece previous to the drilling operation, the accuracy required as regards the relation of one hole to the other, and in regard to the surfaces of the piece itself. The number of duplicate pieces to be drilled must also be considered, and, in some cases, the material.

The simplest kind of drill jig that could be used for the case taken as an example would be the one illustrated in Fig. 2, which simply consists of a flat plate of uniform thickness of the same outline as the piece to be drilled, and provided with holes for guiding the drill. Such a jig would be termed a jig-plate. For small pieces, the jig-plate would be made of machine steel and casehardened, or from tool steel and hardened. For larger work, a machine-steel plate can also be used, but in order to avoid the difficulties which naturally would arise from hardening a large plate, the holes are simply bored larger than the required size of drill, and are provided with lining bushings to guide the drill, as shown in Fig. 3. It would not be necessary, however, to have the jig-plate made from steel, for large work, as a cast-iron plate provided with tool steel or machine-steel guiding bushings would answer the purpose just as well, and be much cheaper. The thickness of the jig-plate varies according to the size of the holes to be drilled and the size of the plate itself.

The holes in the jig in Fig. 2 and in the bushings in the jig in Fig. 3 are made the same size as the hole to be drilled in the work, with proper clearance for the cutting tools. If the size and location of the holes to be drilled are not very important as regards accuracy, it is sufficient to simply drill through the work with a full-sized drill guided by the jig-plate, but when a nice, smooth, standard-sized hole is required, the holes in the work must be reamed. The hole is first spotted by a spotting drill, which is of exactly the same size as the reamer used for finishing, and which nicely fits the hole in the jig-plate or bushing. Then a so-called reamer drill, which is 0.010 inch, or less, smaller in diameter than the reamer, is put through, leaving only a slight amount of stock for the reamer to remove, thereby obtaining a very satisfactory hole. Sometimes a separate loose bushing is used for each one of these operations, but this is expensive and also unnecessary, as the method described gives equally good results.

By using the rose reaming method very good results will also be obtained. In this case two loose bushings besides the lining bushing will be used. These bushings were described and tabulated in a preceding chapter. The drill preceding the rose chucking reamer is $\frac{1}{16}$ inch smaller than the size of the hole. This drill is first put through the work, a loose drill bushing made of steel being used for guiding the drill. Then the rose chucking reamer is employed, using, if the hole in the jig be large, a loose bushing made of cast iron.

When dimensioning the jig on the drawing, dimensions should always be given from two finished surfaces of the jig to the center of the holes, or at least to the more important ones. In regard to the holes, it is not sufficient to give only the right angle dimensions, *a*, *b*, *c*, and *d*, etc., Fig. 2, but the radii between the various holes must also be given. If there are more than two holes, the radii should always be given between the nearest holes and also between the holes that bear a certain relation to one another, as, for instance, between centers of shafts carrying meshing gears, sprockets, etc. This will prove a great help to the toolmaker. In the case under consideration, the dimensions ought to be given from two finished sides of the work to the centers of the holes, and also the dimension between the centers of the holes to be drilled.

When using a simple jig, made as outlined in Figs. 2 and 3, this jig is simply laid down flat on the work and held against it by a C-clamp, a wooden clamp, or, if convenient, held right on the drill-press table by means of a strap or clamp, as shown in Fig. 4. Here two pieces of the work are shown beneath the jig-plate, both being drilled at one time.

Improving the Simple Form of Jig. — The first improvement that could be made on the jig shown in Fig. 3 would be the placing of locating points in the jig-plate in the form of pins, as shown in Fig. 5, in which the dotted lines represent the outline of the work. The plate need not necessarily have the shape shown in Fig. 5, but may have the appearance shown in Fig. 6, according to the conditions.

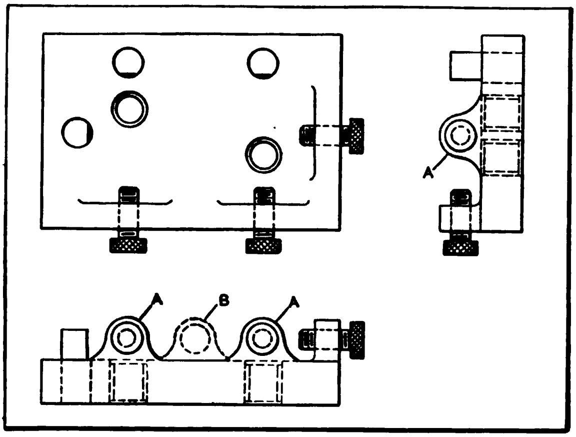


Fig. 7. Simple Jig with Locating Screws Holding the Work in Place

The adding of the locating points will, of course, increase the cost of the jig, but the amount of time saved in using the jig will undoubtedly make up for the added expense of the jig, provided a fair number of pieces is to be drilled; besides a great advantage is gained in that the holes will always be located in the same relation to the two sides resting against the locating pins on all the pieces drilled. The locating pins are flattened off to a depth of $\frac{1}{16}$ inch from the outside circumference, and dimensions should be given from the flat to the center of the pin holes and to the center of the nearest or the most important of the holes to be drilled in the jig. The same strapping or clamping arrangements for the jig and work, as mentioned for the simpler form of jig, may be employed.

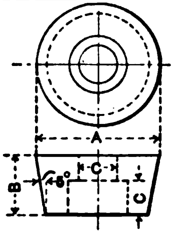
Improving the Jig by Adding Locating Screws. — The next step toward improving the jig under consideration would be to provide the jig with locating screws, as shown in Fig. 7. By the addition of these, the locating arrangements of the jig become complete, and the piece of work will be prevented from shifting or moving sideways. These locating screws are placed so that the clamping points come as nearly opposite to some bearing points on the work as possible. In order to provide for locating set-screws in our present jig, three lugs or projections *A* are added which hold the set-screws. If possible the set-screw lugs should not reach above the surface of the work, which should rest on the drill-press table when drilling the holes.

The present case illustrates the difficulty of giving exact rules for jig design. Two set-screws are used on the long side of the work, but in a case like this, where the piece is comparatively short and stiff, one lug and set-screw, as indicated by the dotted lines at *B* in Fig. 7, would be fully sufficient. The strain of the set-screw placed right between the two locating pins will not be great enough to spring the piece out of shape. When the work is long and narrow, two set-screws are required on the long side, but, in the case illustrated, two lugs would be considered a wasteful design.

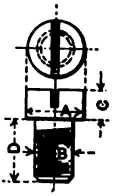
Providing Clamps and Feet for the Jig. — The means by which the work has been clamped or strapped to the jig when drilling in the drill press (see Fig. 4) have not been integral parts of the jig in the simple types shown. If clamping arrangements that are integral parts of the jig are to be added, the next improvement would be to add four legs in order to raise the jig-plate enough above the surface of the drill-press table to get the required space for such clamping arrangements. The completed jig of the best design for rapid manipulation and duplicate work would then have the appearance shown in Fig. 8. The jig here is provided with a handle cast integral with the jig body, and with a clamping strap which can be pulled back for removing and inserting the work. Instead of having the legs solid with the jig, as shown in Fig. 8, loose legs, screwed in place, are sometimes used, as shown in Fig. 9.

These legs are round and provided with a shoulder *A*, preventing them from screwing into the jig-plate. A headless screw or pin through the edge of the circumference of the threads at the top prevents the studs from becoming loose. These loose legs are usually made of machine steel or tool steel, the bottom end being hardened and then ground and lapped, so that all four legs are of the same length. It is the practice of many toolmakers not to thread the legs into the jig body, but simply to provide a plain surface on the end of the leg, which enters into the jig-plate, and is driven into place. This is much easier, and there is no reason why, for almost all kinds of work, jigs provided with legs attached in this manner should not be equally durable.

Standard Jig Feet

	A	*B*	*C*	*A*	*B*	*C*
	3/8	3/16	1/8	1 3/16	1 3/32	7/32
	7/16	7/32	9/64	3/4	3/8	1/4
	1/2	1/4	5/32	7/8	7/16	9/32
	9/16	9/32	11/64	1	1/2	5/16
	5/8	5/16	3/16	....	....	....

Screws for Jig Feet

	A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
	0.160	1/8	0.110	9/32	0.299	7/32	0.192	7/16
	0.191	9/64	0.123	5/16	0.343	1/4	0.219	15/32
	0.213	5/32	0.137	11/32	0.386	9/32	0.246	1/2
	0.233	11/64	0.150	3/8	0.426	5/16	0.273	17/32
	0.256	3/16	0.164	13/32	.....	....	.....	....

Jig feet are also made of the form shown in the accompanying table, where a separate screw is used for holding the jig feet to the jig body.

When jigs are made of machine or tool steel, and feet are

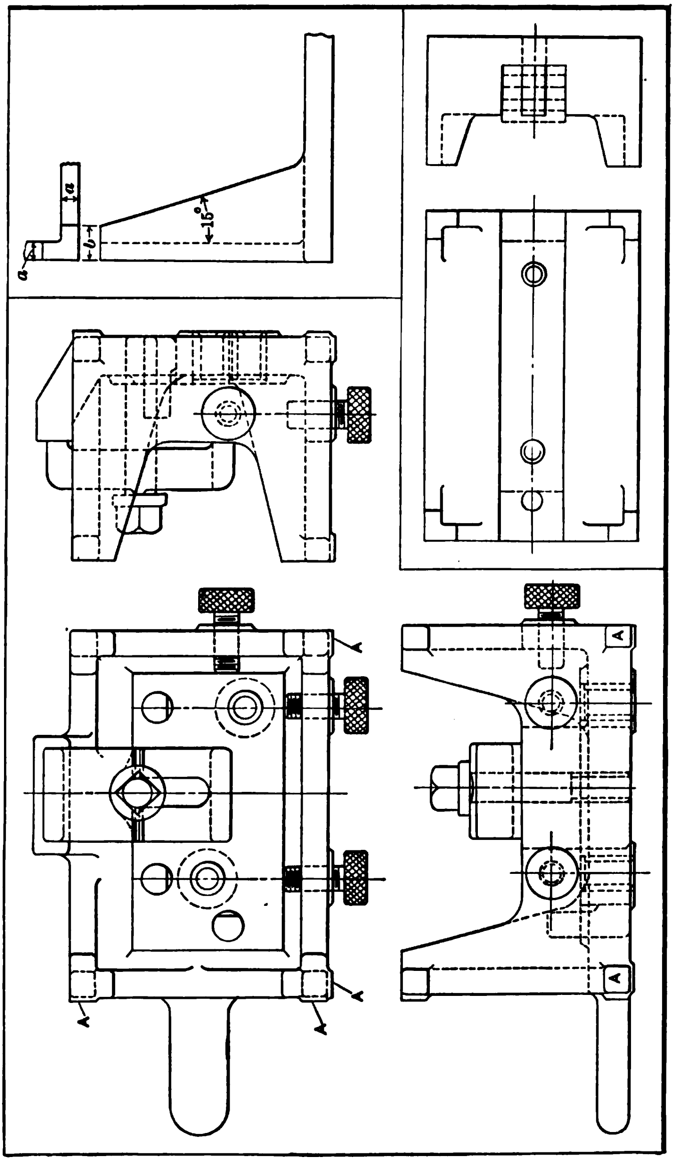


Fig. 8. Complete Jig for Rapid Duplicate Work; Design of Legs for Cast-iron Jig Bodies; and Form of Jig that may be Used for Drilling a Number of Pieces Simultaneously

required, the only way to provide them is to insert loose feet. In the case of cast-iron jigs, however, solid legs cast in place are preferable. The solid legs cast in place generally have the appearance shown in the upper right-hand corner of Fig. 8. The two webs of the leg form a right angle, which, for all practical purposes, makes the leg fully as strong as if it were solid. The leg is tapered 15 degrees, as a rule, as shown in the engraving, but this may be varied according to conditions. The thickness of the leg varies according to the size of the jig, the weight of the work, and the pressure of the cutting tools, and depends also upon the length of the leg. The length *b* on top is generally made one and one-half times *a*. As an indication of the size of the legs required, it may be said that for smaller jigs, up to jigs with a face area of 6 square inches, the dimension *a* may be made from $\frac{5}{16}$ to $\frac{3}{8}$ inch; for medium-sized jigs, $\frac{1}{2}$ to $\frac{5}{8}$ inch; for larger-sized jigs, $\frac{3}{4}$ to $1\frac{1}{2}$ inch; but, of course, these dimensions are simply indications of the required dimensions. As to the length of the legs, the governing condition, evidently, is that they must be long enough to reach below the lowest part of the work and the clamping arrangement, as clearly indicated in the design in Fig. 8.

If a jig is to be used in a multiple-spindle drill, it should be designed a great deal stronger than it is ordinarily designed when used for drilling one hole at a time. This is especially true if there is a large number of holes to drill simultaneously. It is evident that the pressure upon the jig in a multiple-spindle drill is as many times greater than the pressure in a common drill press as the number of drills in operation at once.

Referring again to Fig. 8, attention should be called to the small lugs *A* on the sides of the jig body which are cast in place for laying out and planing purposes. The handle should be made about 4 inches long, which permits a fairly good grip by the hand. The design of the jig shown is simple, and fills all requirements necessary for producing work quickly and accurately; at the same time, it is strongly and rigidly designed. Locating points of a different kind from those shown can, of course, be used; and the requirements may be such that adjustable locating points, as described in a preceding chapter, may be required. A more quick-acting, but, at the same time, a far more complicated clamping arrangement might be used, but the question is whether the added increase in the rapidity of manipulation offsets the expense thus incurred.

A question which the designer should always ask himself is: Can more than one piece be drilled at one time? In the present case, the locating pins can be made longer, or, if there is a locating wall, it can be made higher, the legs of the jig can be made longer, and the screw holding the clamp can also be increased in length. If the pieces of work are thick enough, set-screws for holding the work against the locating pins can be placed in a vertical line, or if the pieces are narrow, they can be placed diagonally, so as to gain space. If the pieces are very thin, the locating might be a more difficult proposition. If they are made of a uniform width, they may simply be put in the slot in the bottom of the jig, as shown in the lower right-hand corner of Fig. 8, or if a jig on the principles of the one shown to the left is used, they might be located sideways by a wedge, as shown in Fig. 10. A couple of lugs *A* would then be added to hold the wedge in place and take the thrust. In both cases the pieces must be pushed up in place endways by hand. If the pieces are not of exactly uniform size and it is desired to drill a number

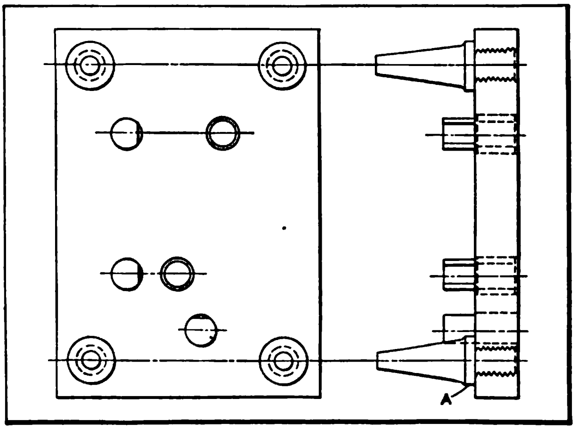


Fig. 9. Legs Screwed into Jig Body

at a time, they must be pushed up against the locating pins by hand from two sides, and the clamping strap must be depended upon to clamp them down against the pressure of the cut, and at the same time prevent them from moving side or endways. If the accuracy of the location of the holes is important, but one piece at a time should be drilled.

Examples of Open Drill Jigs. — A typical example of an open drill jig, very similar to the one just developed and explained, is shown in Fig. 11. The work is located against the three locating pins *A*, and held in place against these pins by the three set-screws *B*. The three straps *C* hold the work securely against the finished pad, in the bottom of the jig. These clamps are so placed that when the work has been drilled and the clamp screws loosened, the clamps will swing around a quarter of a turn, allowing the work to be lifted directly from the jig and a new piece of work inserted; then the clamps are again turned around into the clamping position, and the screws tightened. These straps are integral parts of the jig; at the same time, they are quickly and easily manipulated, and do not interfere with the rapid removal and insertion of the work. The strength and rigidity of the feet in proportion to the jig should be noted, this strength being obtained by giving proper shape to the feet, without using an unnecessary quantity of metal.

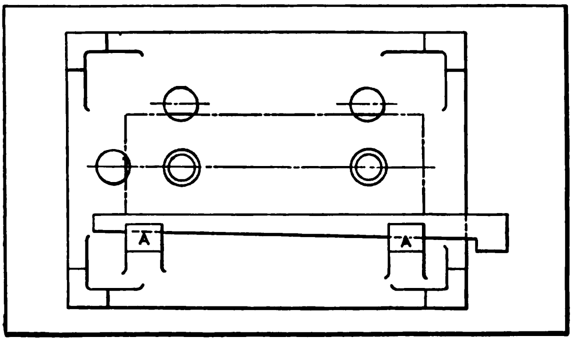


Fig. 10. Jig with Wedge for Holding the Work

The jig in Fig. 11 is also designed to accommodate the component part of the work when it is to be drilled. When this is done, the work is held on the back side of the jig, shown in Fig. 12.

This side is also provided with feet, and has a finished pad against which the work is held. The locating pins extend clear through the central portion of the jig body, and, consequently, will locate the component part of the work in exactly the same position as the piece of work drilled on the front side of the jig. The same clamping straps are used, the screws being simply put in from the opposite side into the same tapped holes as are used when clamping on the front side of the jig. The four holes *D* are guide holes for drilling the screw holes in the work, these being drilled the body size of the bolt in one part, and the tap drill size in the component part. The lining bushing in the holes *D* serves as a drill bushing for drilling the body size holes. The loose bushing *E*, Fig. 11, is used when drilling the tap holes in the component part, the inside diameter of this bushing being the tap drill size, and the outside diameter a good fit in the lining bushing. The two holes *F*, Fig. 12, are provided with drill bushings and serve as guides when drilling the dowel pin holes, which are drilled below size, leaving about 0.010 inch, and are reamed out after the two component parts of the work are put together. The two holes shown in the middle of the jig in Fig. 11, which are provided with lining bushings, and also with loose bushings, as shown inserted in Fig. 12, may be used for

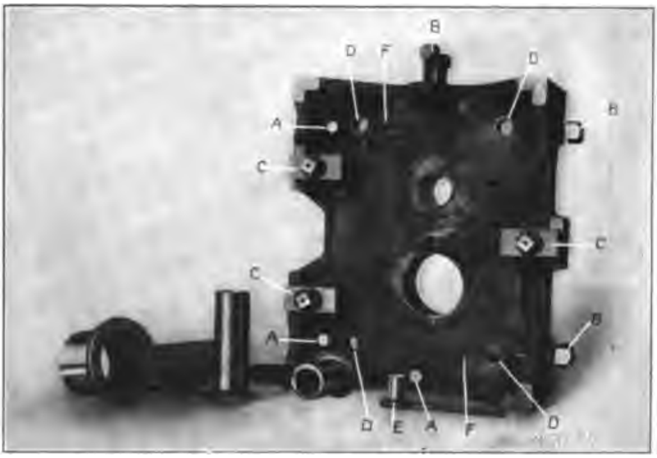


Fig. 11. Example of Open Drill Jig. View showing Front Side

drilling and reaming the bearing holes for the shafts passing through the work. In this particular case, however, they are used only for rough-drilling the holes, to allow the boring-bars to pass through when finishing the work by boring in a special boring jig, after the two parts of the work have been screwed together.

The large bushings shown beside the jig in Fig. 11 are the loose bushings shown in place in Fig. 12. It will be noted that the bushings are provided with dogs for easy removal, as explained in a preceding chapter. As the central portion of the jig body is rather thin, it will be seen from Fig. 12 that the bosses for the central holes project outside of the jig body in order to give a long enough bearing to the bushings. This, of course, can be done only when such a projection does not interfere with the work. The bosses, in this particular case, also serve another purpose. They make the jig "fool-proof," because the pieces drilled on the side of the jig shown in Fig. 11 cannot be put on the side shown in Fig. 12, the bosses preventing the piece from being placed in position in the jig.

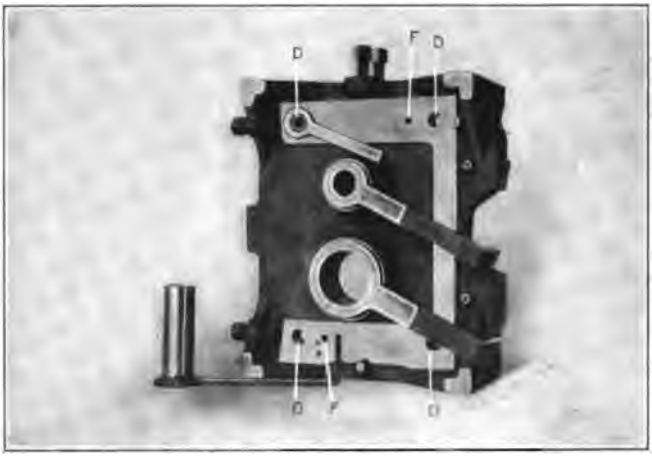


Fig. 12. Rear View of Drill Jig shown in Fig. 11

Attention should be called to the simplicity of the design of this jig. It simply consists of a cast-iron plate, with finished seats, and feet projecting far enough to reach below the work when drilling, three dowel pins, set-screws for bringing the work up against the dowel pins, three clamps, and the necessary bushings. The heads of all the set-screws and bolts should, if possible, be made the same size, so that the same wrench may be used for tightening and unscrewing all of them. It can also be plainly seen from the halftones that there are no unnecessarily finished surfaces on the jig, a matter which is highly important in economical production of tools.

Another example of an open drill jig, similar in design to the one just described, is shown in Fig. 13. The work to be drilled in this jig is shown at *A* and *B* at the right-hand side of the jig. In this case, the work is located from the half-circular ends. The pieces *A* and *B* are component parts and, when finished, are screwed together. The piece *A* is located against three dowel pins, and pushed against them by set-screws *C*, and held in position by three clamping straps, as shown in Fig. 14. In this case, the straps are provided with oblong slots as indicated, and when the clamp screws are loosened the clamps are simply pulled backward, permitting the insertion and removal of the work without interference. It would improve this clamping arrangement to place a stiff helical spring around the screws under each strap, so that the straps would be prevented from falling down to

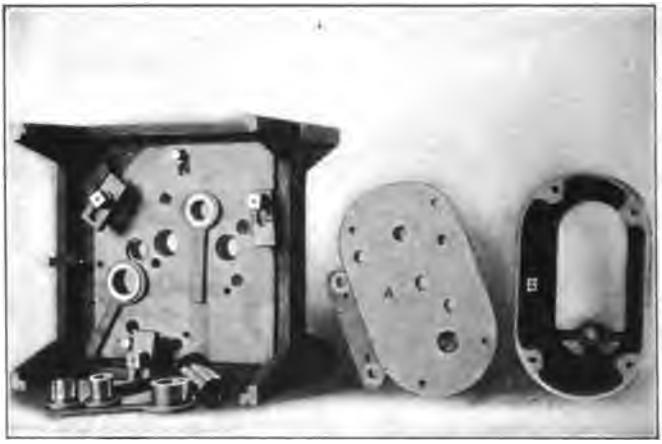


Fig. 13. Drill Jig Used for Drilling Work shown to the Right

the bottom of the jig when the work was removed. At the same time this would prevent the straps from swiveling around the screws when not clamped.

In Fig. 15, the part *B* in Fig. 13 is shown clamped in position for drilling, the opposite side of the jig being used for this purpose. In jig design of this kind it is necessary to provide some means so that the parts *A* and *B* will be placed each on the correct side of the jig, or, as mentioned, the jig should be made "fool-proof." In the present case, the parts cannot be exchanged and placed on the wrong side, because the cover or guard *B* cannot be held by the three straps shown in Fig. 14, as the screws for the straps are not long enough. On the other hand, the piece *A* could not be placed on the side shown in Fig. 15, because the long bolt and strap used for clamping on this side would interfere with the work.

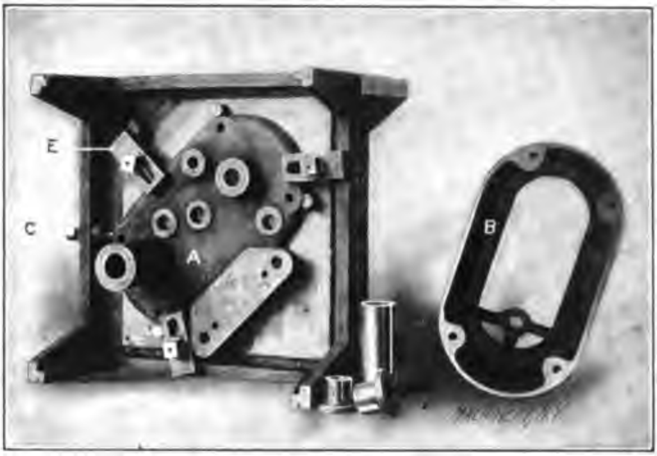


Fig. 14. Drill Jig shown in Fig. 13 with Work in Place

It may appear to be a fault in design that three straps are used to fasten the piece *A* in place, and only one is employed for holding piece *B*. This difference in clamping arrangement, however, is due to the different number and the different sizes of holes to be drilled in the different pieces. The holes in the piece *A* are larger and the number of holes is greater, and a heavier clamping arrangement is, therefore, required, inasmuch as the thrust on the former is correspondingly greater, the multiple-spindle drill being used for drilling the holes. If each hole were drilled and reamed individually, the design of the jig could have been comparatively lighter.

In the design shown, the locating of each piece individually in any but the right way is also taken care of. The piece *A*, which is shown in place in the jig, Fig. 14, could not be swung around into another position, because the strap and screw at *E* would interfere. For the same reason, the cover or guard *B* could not be located except in the right way. As shown in Fig. 15, the strap and screw would have to be detached from the jig in order to get the cover in place, if it were turned around. The locating pins for the work pass clear through the body of the jig, and are used for locating both pieces. The pieces are located diagonally in the jig, because, by doing so, it is possible to make the outside dimensions of the jig smaller. In this particular case the parts are located on the machine to which they belong, in a diagonal direction, so that the additional advantage is gained of being able to use the same dimensions for locating the jig holes as are used on the drawing for the machine details themselves. This also tends to eliminate mistakes in making the jigs.

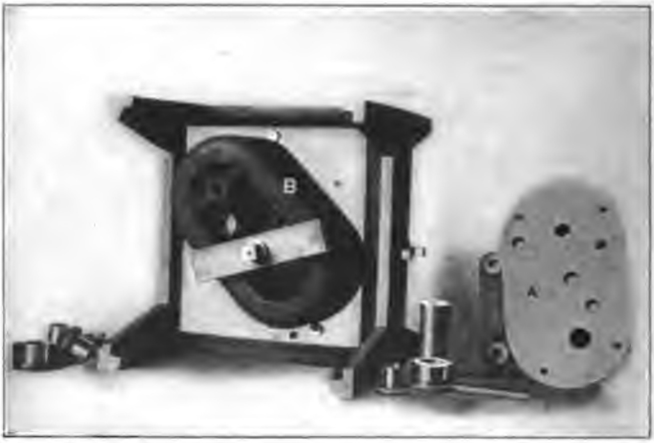


Fig. 15. Rear View of Drill Jig shown in Fig. 13, with Cover to be Drilled in Place

Sometimes, when more or less complicated mechanisms are composed of several parts fitted together and working in relation to each other, as, for instance, friction clutches, one jig may be made to serve for drilling all the individual parts, by the addition of a few extra parts applied to the jig when different details of the work are being drilled. In Figs. 16, 17, and 18, such a case is illustrated. The pieces *A*, *B*, and *C*, in Fig. 16, are component parts of a friction clutch, and the jig in which these parts are being drilled is shown in the same figure, to the left. Suppose now that the friction expansion ring *A* is to be drilled. The jig is bored out to fit the ring before it is split and when it is only rough-turned, leaving a certain number of thousandths of an inch for finishing. The piece is located, as shown in Fig. 17, against the steel block *D* entering into the groove in the ring, and is then held by three hook-bolts, which simply are swung around when the ring is inserted or removed. The hook-bolts are tightened by nuts on the back side of the jig. Three holes marked *E* in Fig. 17 are drilled simultaneously in the multiple-spindle drill, and the fourth hole *F* (see Fig. 16) is drilled by turning the jig on the side. The steel block *D*, Fig. 17, is hardened, and has a hole to guide the drill when passing through into the other side of the slot in the ring. The block is held in place by two screws and two dowel pins.

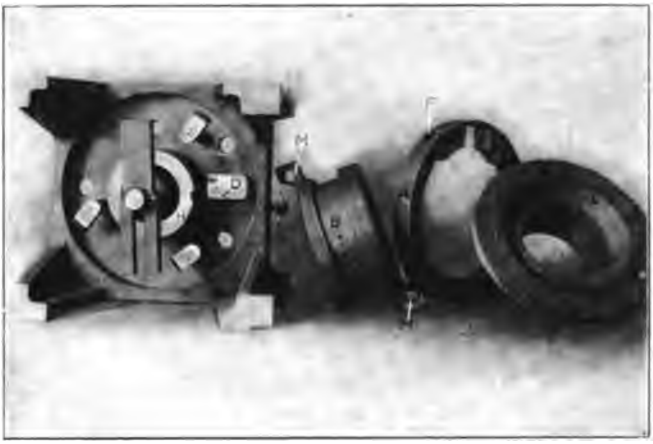


Fig. 16. Drill Jig for Parts of Friction Clutches shown at the Right

When drilling the holes in the lugs in the friction sleeve *B*, Fig. 16, the block *D* and the hook-bolts are removed. It may be mentioned here, although it is a small matter, that these parts should be tied together when removed, and there should be a specified place where all the parts belonging to a particular jig should be kept when not in use. The friction sleeve *B* fits over the collar *G*, Fig. 18. This collar is an extra piece, belonging to the jig, and used only when drilling the friction sleeve; it should be marked with instructions for what purpose it is used. The collar *G* fits over the projecting finished part *H* in the center of the jig, and is located in its right position by the keyways shown. The keyway in the friction sleeve *B*, which must be cut and placed in the right relation to the projecting lugs before the piece can be drilled, locates the sleeve on the collar *G*, which is provided with a corresponding keyway. A flange on the collar *G*, as shown more plainly at *L* in Fig. 18, locates the friction sleeve at the right distance from the bottom of the jig, so that the holes will have a proper location sideways. Two collars, *G* and *L*, are used for the same piece *B*, this being necessary because the holes *M* and *M* in the projecting lugs shown in Fig. 16 are not placed in the same relation to the sides of the friction sleeve. The collars are marked to avoid mistakes, and corresponding marks on the jig provided so as to

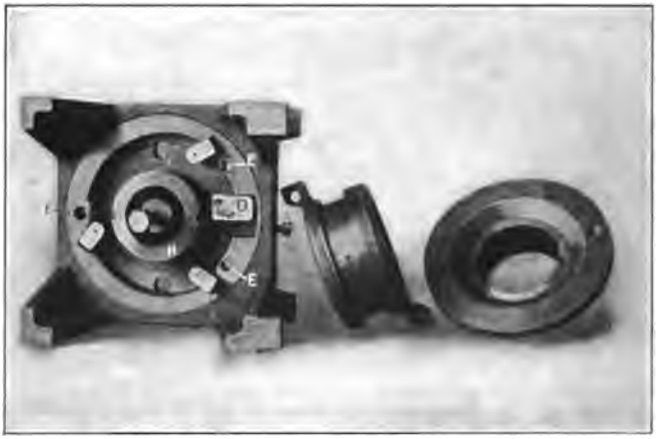


Fig. 17. Drill Jig shown in Fig. 16, with One of the Pieces in Place

assure proper location. The friction sleeve is clamped in place by a strap which, in this case, does not form an integral part of the jig. This arrangement, however, is cheaper than it would have been to carry up two small projections on two sides of the jig and employ a swinging leaf and an eye-bolt, or some arrangement of this kind. Besides, the strap is rather large, and could not easily get lost. The jig necessarily has a number of loose parts, on account of being designed to accommodate different details of the friction clutch.

The friction disks *C*, in Fig. 16, when drilled, fit directly over the projecting finished part *H* of the jig, and are located on this projection by a square key. The work is brought up against the bottom of the jig and held in this position by the strap shown in Fig. 18 for holding the friction sleeve. The bushings of different sizes shown in Fig. 18 are used for drilling the different sized holes in the different parts.

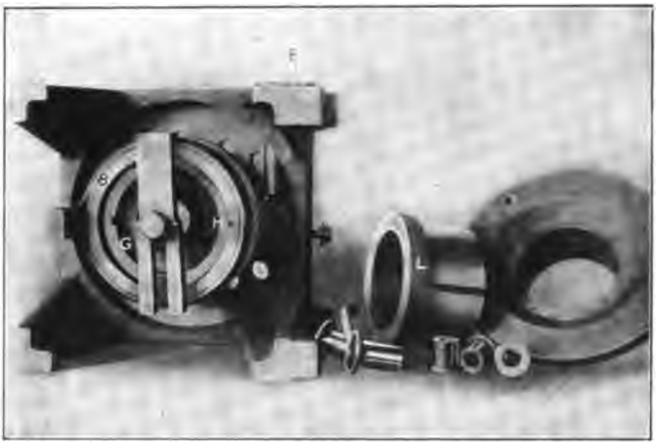


Fig. 18. Drill Jig shown in Fig. 16 used for Drilling Friction Sleeve

In all the various types of drill jigs described, the thrust of the cutting tools is taken by the clamping arrangement. In many cases, however, no actual clamping arrangements are used, but the work itself takes the thrust of the cutting tools, and the locating means are depended upon to hold the piece or jig in the right position when performing the drilling operation.

It may be well to add that loose bushings ought to be marked with the size and kind of cutting tool for which they are intended; and the corresponding place in the jig body where they are to be used should be marked so that the right bushing can easily be placed in the right position.

A few more examples of open drill jig designs of various types may prove instructive. In Fig. 19 are shown two views of a jig for drilling two holes through the rim of a handwheel. To the left is shown the jig itself and to the right the jig with the handwheel mounted in place, ready for drilling. As shown, the handwheel is located on a stud through its bore, and clamped to the jig by passing a bolt through the stud, this bolt being provided with a split washer on the end. The split washer permits the easy removal of the handwheel when drilled, and the putting in place of another handwheel without loss of time. The handwheel is located by two set-screws *B* passing through two lugs projecting on each side of a spoke in the handwheel, the set-screws *B* holding the handwheel in position, while being drilled, by clamping against the sides of the spoke. The jig is fastened on the edge of the drill-press table, in a manner similar to that indicated in the illustration, so that the table does not interfere

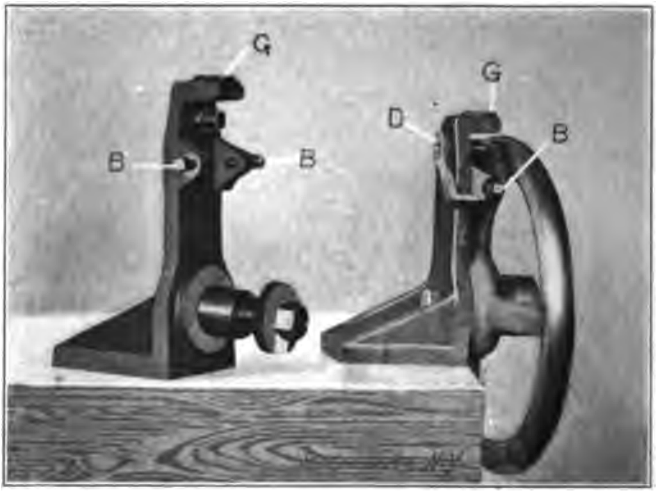


Fig. 19. Drill Jig for Holes in Rim of Handwheel

with the wheel. The vertical hole, with the drill guided by bushing *G*, is now drilled in all the handwheels, this hole being drilled into a lug in the spoke held by the two set-screws *B*. When this hole is drilled, the jig is moved over to a horizontal drilling machine, and the hole *D* is drilled in all the handwheels, the jig being clamped to the table of this machine in a manner similar to that on the drill press.

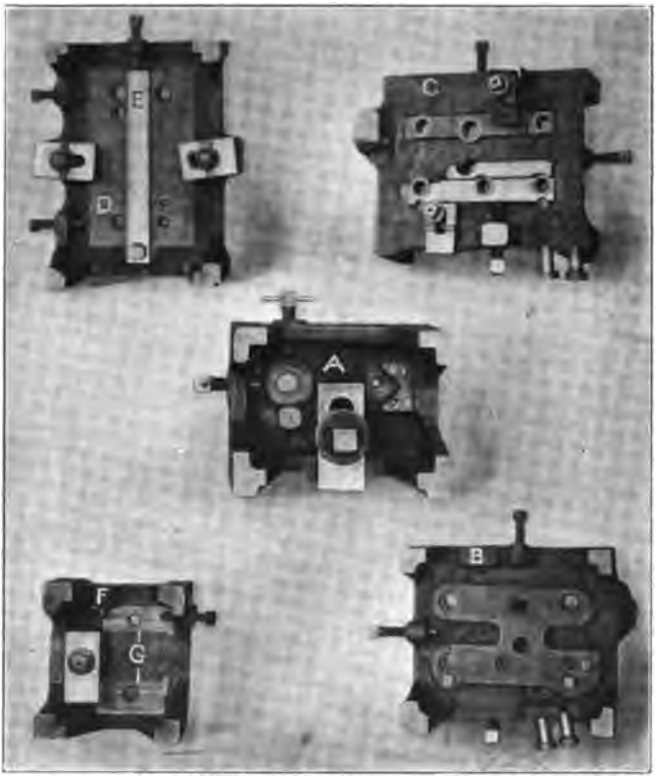


Fig. 20. Miscellaneous Examples of Open Drill Jigs

In Fig. 20, at *A*, an open drill jig of a type similar to those shown in Figs. 11 and 13, is shown. This jig, however, is provided with a V-block locating arrangement. An objectionable feature of this jig is that the one clamping strap is placed in the center of the piece to be drilled. Should this piece be slender, it may cause it to bend, as there is no bearing surface under the work, at the place where the clamp is located, for taking the thrust of the clamping pressure.

At *B* and *C* in the same illustration are shown the front and back views of a drill jig, where the front side *B* is used for drilling a small piece located and held in the jig as usual; and the back side *C*, which is not provided with feet, is located and applied directly on the work itself in the place where the loose piece is to be fastened, the work in this case being so large that it supports the jig, instead of the jig supporting the work.

At *D* in the same illustration is shown a jig for locating work by means of a tongue *E*. This tongue fits into a corresponding slot in the work. This means for locating the work was referred to more completely in connection with locating devices. Finally, at *F*, is shown a jig where the work is located by a slot *G* in the jig body, into which a corresponding tongue in the work fits.

CHAPTER XII

DESIGN OF CLOSED OR BOX JIGS

In the preceding chapter, the subject of the design of open drill jigs has been dealt with. In the present chapter it is proposed to outline the development of the design of closed or box jigs.

Assume that the holes in a piece of work, as shown in Fig. 1, are to be drilled. Holes *A* are drilled straight through the work, while holes *B* and *C* are so-called "blind holes," drilled into the work from the opposite sides. As these holes must not be drilled through, it is evident that the work must be drilled from two sides, and the guiding bushings for the two blind holes must be put in opposite sides of the jig. The simplest form of jig for this work is shown in Fig. 2. The piece of work *D* is located between the two plates *E*, which form the jig, and which, if the jig is small, are made of machine steel and casehardened. If the jig is large these plates are made of cast iron. The work *D* is simply located by the outlines of the plates, which are made to the same dimensions, as regards width, as the work itself. The plates are held in position in relation to each other by the guiding dowel pins *F*. These pins are driven into the lower plate and have a sliding fit in the upper one. In some cases, blocks or lugs on one plate would be used to fit into a slot in the other plate instead of pins. These minor changes, of course, depend upon the nature of the work, the principle involved being that some means must be provided to prevent the two plates from shifting in relation to each other while drilling. The whole device is finally held together by clamps of suitable form. The holes *A* may be drilled from either side of the jig, as they pass clear through the work, and the guides for the drills for these holes may, therefore, be placed in either plate. Opposite the bushings in either plate a hole is drilled in the other plate for clearance for the drill when passing through, and for the escape of the chips.

The two plates should be marked with necessary general information regarding the tools to be used, the position of the plates, etc., to prevent mistakes by the operator. It is also an advantage, not to say a necessity, to use some kind of connection between the plates in order to avoid such mistakes as, for instance, the placing of the upper plate in a reversed position, the wrong pins entering into the dowel pin holes. This, of course, would locate the holes in a faulty position. Besides, if the upper plate be entirely loose from the lower, it is likely to drop off when the jig is stored, and get lost. Some means of holding the two parts together, even when not in use, or when not clamped down on the work, should therefore be provided. Such a means is employed in Fig. 2, where the screw *G* enters into the guiding dowel pin at the left and holds the upper plate in place. A pin *H*, fitting into an elongated slot in the dowel pin, as shown at the left, could also be used instead of the screw. The design shown presents the very simplest form of box jig, consisting, as it does, of only two plates for holding the necessary guiding arrangements, and two pins or other means for locating the plates in relation to each other.

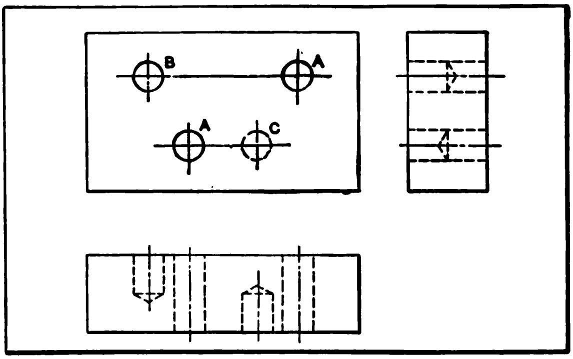


Fig. 1. Work to be Drilled

In manufacturing, where a great number of duplicate parts would be encountered, a jig designed in the simple manner shown in Fig. 2 would, however, be wholly inadequate. The simplest form of a jig that would be used in such a case would be one in which some kind of locating means is employed, as indicated in Fig. 3, where three pins are provided, two along the side of the work and one for the end of the work, against which the work

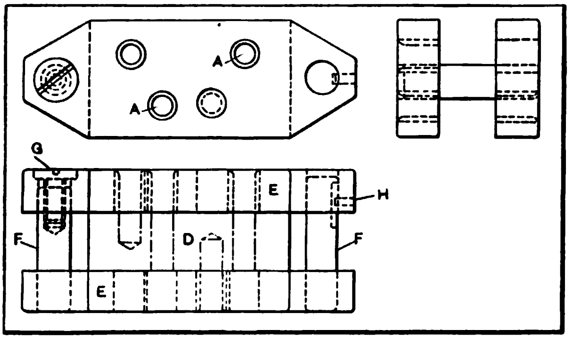


Fig. 2. Simple Form of Closed Jig for Drilling Work shown in Fig. 1

may be pushed prior to the clamping together of the two jig-plates. In this illustration, the jig bushings are not shown in the elevation and end view, in order to avoid confusion of lines. The next improvement to which this jig would be subjected would

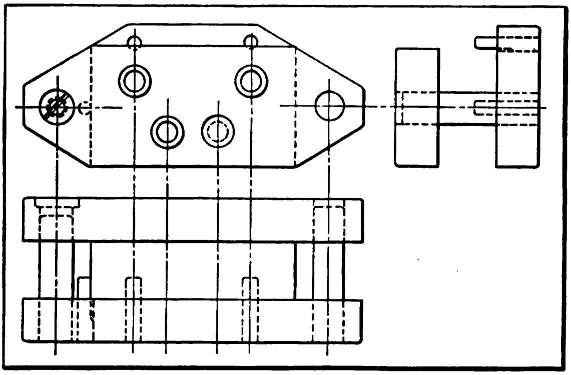


Fig. 3. Locating Pins added to Jig

be the adding of walls at the end of the jig and the screwing together of the upper and lower plate, the result being a jig as shown in Fig. 4. This design presents a more advanced style of closed jig — a type which could be recommended for manufacturing purposes. While the same fundamental principles are still in evidence, this jig embodies most of the requirements necessary for rapid work. This design provides for integral clamping means within the jig itself, provided, in this case, by the screws *J*. The upper plate *K* is fastened to the walls of the lower plate *L* by four or more screws *M* and two dowel pins *N*. The cover *K* could also be put on, as shown in Fig. 5, by making the two parts a good fit at *O*, one piece being tongued into the other. This gives greater rigidity to the jig. In this jig, also, solid locating lugs *F* are used instead of pins.

Referring again to Fig. 4, by providing a swinging arm *P* with a set-screw *Q*, the work can be taken out and can be inserted from the side of the jig, which will save making any provisions for taking off or putting on the top cover for every piece being drilled. If there is enough clearance between the top cover and the piece being drilled, the screw *Q* could, of course, be mounted in a solid lug, but it would not be advantageous to have so large a space between the top plate and the work, as the drill would have to extend unguided for some distance before it would reach the work. The set-screws *Q* and *U* hold the work against the locating points, and the set-screws *J* on the top of the jig, previously referred to, hold the work down on the finished pad *R* on the bottom plate. These screws also take the thrust when the hole *C* is drilled from the bottom side. It is immaterial on which side the bushings for guiding the drills for the two holes *A* are placed, but by placing them in the cover rather than in

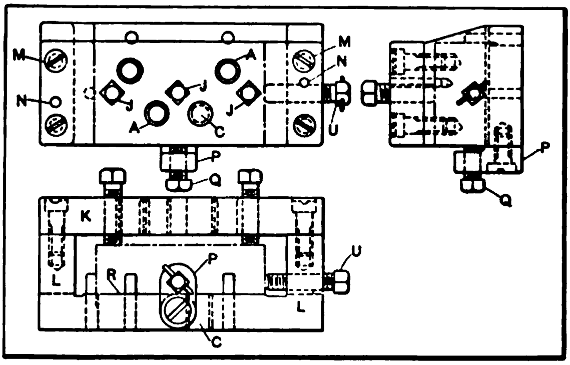


Fig. 4. Jig Suitable for Manufacturing Purposes

the bottom plate, three out of the four bushings will be located in the top part, and when using a multiple-spindle drill, the face *R* will take the greater thrust, which is better than to place the thrust on the binding screws *J*. In the designs in Figs. 4 and 5 the whole top and bottom face of the jig must be finished, or a strip marked *f* in Fig. 6, at both ends of the top and bottom surfaces, must be provided, so that it can be finished, and the jig placed on parallels *D* as illustrated.

While the jig itself, developed so far, possesses most of the necessary points for rapid production and accurate work, the use of parallels, as indicated in Fig. 6, for supporting the jig when turned over so that the screw-heads of the clamping screws point downward, is unsatisfactory. Therefore, by adding feet to the jig, as shown in Fig. 7, the handling of the jig will be a great deal more convenient. The adding of the protruding handle *S* will still further increase the convenience of using the jig. The design in Fig. 7 also presents an improvement over that in Fig. 4, in that, besides the adding of feet and handle, the leaf or strap *E* is used for holding screw *Q* instead of the arm *P*. This latter is more apt to bend if not very heavy, and would then bring the set-screw in an angle upwards, which would have a tendency to tilt the work. The strap can be more safely relied upon to clamp the work squarely. Two set-screws *J* are shown for holding the work in place. The number of these set-screws,

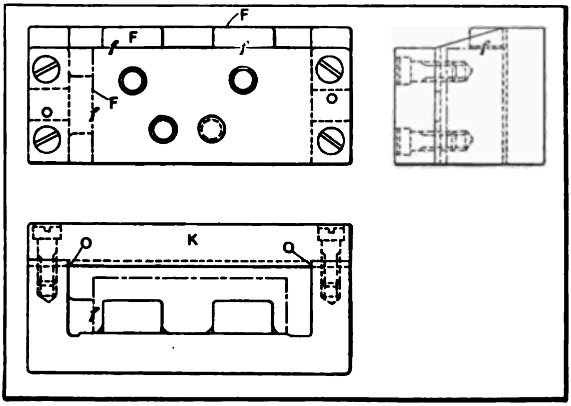


Fig. 5. Alternative Design of Jig shown in Fig. 4

of course, depends entirely upon the size of the work and the size of the holes to be drilled. Sometimes one set-screw is quite sufficient, which, in this case, would be placed in the center, as indicated by the dotted lines in Fig. 4.

The type of jig shown in Fig. 7 now possesses all the features generally required for a good jig, and presents a type which is largely used in manufacturing plants, particularly for medium and heavy work. The jig shown in Fig. 8, however, represents another type, somewhat different from the jig in Fig. 7. The jig in Fig. 7 is composed of two large separate pieces, which, for large jigs, means two separate castings, involving some extra expense in the pattern-shop and foundry. The reason for making the jig in two parts, instead of casting it in one, is because it makes it more convenient when machining the jig. The locat-

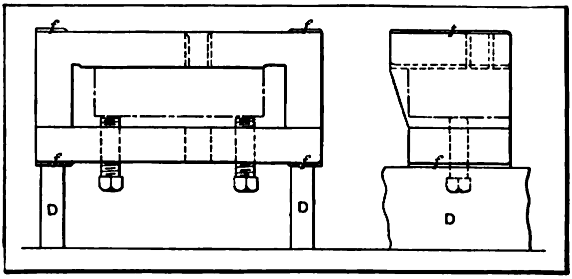


Fig. 6. Jig in Fig. 4 used in Combination with Two Parallels

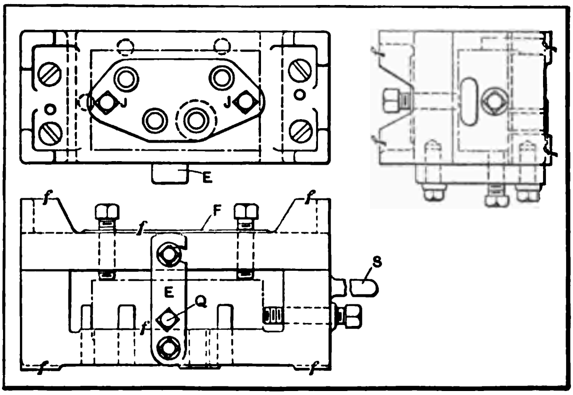


Fig. 7. Jig improved by Adding Feet opposite Faces containing Drill Bushings

ing points, however, are somewhat hidden from view when the piece is inserted. The jig shown in Fig. 8 consists of only one casting *L*, provided with feet, and resembles an open drill jig. The work is located in a manner similar to that already described, and the leaf *D*, wide enough to take in all the bushings except the one for the hole that must be drilled from the opposite side, is fitted across the jig and given a good bearing between the lugs in the jig wall. It swings around the pin *E* and is held down by the eye-bolt *F* with a nut and washer. Sometimes a wing-nut is handier than a hexagon nut. Care should be taken that the feet reach below the top of the nut and screw. The set-screw *G* holds the work down, and takes the thrust when the hole from the bottom side is drilled. The three holes *A*, *A* and *B* are drilled from the top so that the thrust of the drilling of these three holes will be taken by the bottom of the jig body *L*. If one set-screw *G* is not sufficient for holding the work in place, the leaf may be made wider so as to accommodate more binding screws.

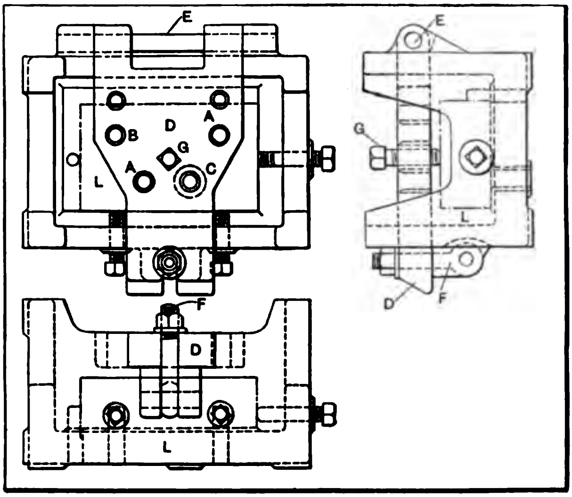


Fig. 8. Alternative Design of Jig in Fig. 7

It is, however, an objectionable feature to place the clamping screws in the bushing plate. If the leaf has not a perfect fit in its seats and on the swiveling pin, the screws will tilt the leaf one way or another, and thus cause the bushings to stand at an angle with the work, producing faulty results. In order to avoid this objectionable feature, a further improvement on the jig, indicated in Fig. 9, is proposed. In the jig body, the locating points and the set-screws which hold the work against the locating pins are placed so that they will not interfere with two straps *G*, which are provided with elongated slots, and hold the work securely in place, also sustaining the thrust from the cutting tools. These straps should be heavily designed, in order to be able to take the thrust of the multiple-spindle drill, because in this case all the bushings, except the one for hole *B*, are placed in the bottom of the jig body. The leaf is made narrower and is not as heavy as the one shown in Fig. 8, because it does not, in this case, take any thrust when drilling, and simply serves the purpose of holding the bushing for hole *B*. The leaves and loose bushing plates for jigs of this kind are generally made of machine steel, but for larger sized jigs they may be made of cast iron. The leaf in Fig. 9 is simply held down by the thumb-screw *H*.

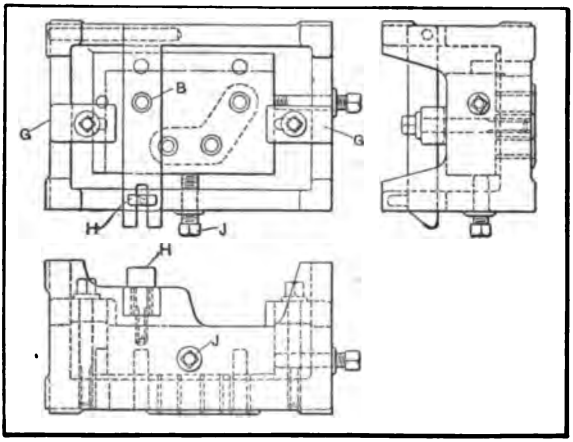


Fig. 9. Jig in which Thrust of Drilling Operations is taken by Clamps

If the hole *B* comes near to one wall of the jig, it may not be necessary to have a leaf, but the jig casting may be made with a projecting lug *D*, as shown in Fig. 10, the jig otherwise being of the same type as the one illustrated in Fig. 9. The projecting part *D*, Fig. 10, is strengthened, when necessary, by a rib *E*, as indicated. Care must be taken that there is sufficient clearance for the piece to be inserted and removed. Once in a while it happens, even with fairly good jig designers, that an otherwise well-designed jig with good locating, clamping, and guiding arrangements, is rendered useless, for the simple reason that there is not enough clearance to allow the insertion of the work.

Fig. 11 shows the same jig as before, but with the additional feature of permitting a hole in the work to be drilled from the end and side as indicated, the bushings *E* and *F* being added for this purpose. The bushings, in this case, extend through the jig wall for some distance, in order to guide the drill closely to the work. Bosses may also be cast on the jig body, as indicated by the dotted lines, to give a longer bearing for the bushings.

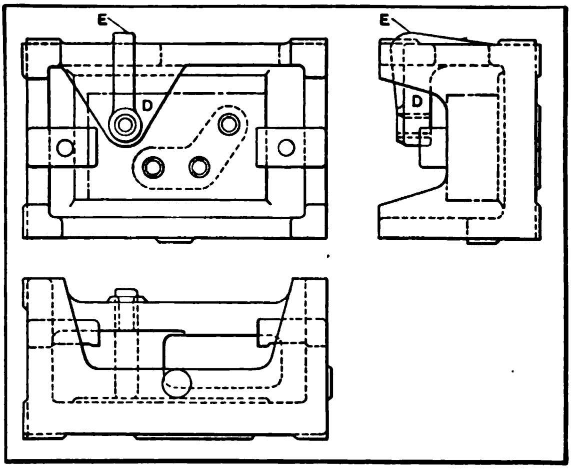


Fig. 10. Modification of Jig Shown in Fig. 9

Feet or lugs are cast and finished on the sides of the jig opposite the bushings, so that the jig can be placed conveniently on the drill-press table for drilling in any direction. When drilling the holes from the bushings *E* and *F*, the thrust is taken by the stationary locating pins. It is objectionable to use set-screws to take the thrust, although in some cases it is necessary to do so. When designing a jig of this type, care must be taken that strapping arrangements and locating points are placed so that they, in no way, will interfere with the cutting tools or guiding means. In this case the strap *H* is moved over to one side in order to give room for the bushings *F* and the set-screw *K*. Strap *G* should then be moved also, because moving the two straps in opposite directions still gives them a balanced clamping action on the work. If the strap *G* had been left in place, with the strap *H* moved sideways, there would have been some tendency to tilt the work.

Sometimes one hole in the work comes at an angle with the faces of the work. In such a case the jig must be made along the lines indicated in Fig. 12, the feet on the sides opposite to where the drill bushings are placed being planed so that their faces will be perpendicular to the axis through the hole *A*. This will, in no way, interfere with the drilling of holes which are perpendicular to the faces of the work, as these can be drilled from the opposite side of the work, the jig then resting on the feet *B*. Should it, however, be necessary to drill one hole at an angle and other holes perpendicular to the face of the work from the same side, an arrangement as shown in Fig. 13 would be used. The jig here is made in the same manner as the jig shown in Fig. 11, with the difference that a bushing *A* is placed at the required angle. It will be seen, however, that as the

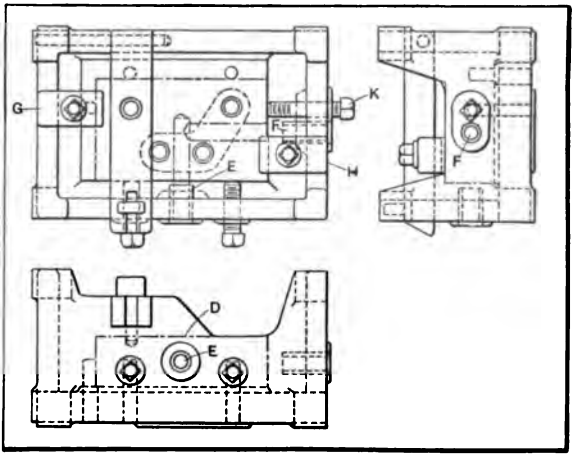


Fig. 11. Jig for Drilling Holes from Two Directions

other holes drilled from the same side must be drilled perpendicularly to the faces of the work, it would not be of advantage to plane the feet so that the hole *A* could be drilled in the manner previously shown in Fig. 12. Therefore the feet are left to suit the perpendicular holes, and the separate base bracket *B*, Fig. 13, is used to hold the jig in the desired inclined position when the hole *A* is drilled.

Stand *B* in Fig. 13 is very suitable for this special work. It is made up as light as possible, being cored at the center, so as to remove superfluous metal. These stands are sometimes provided with a clamping device for holding the jig to the stand. Special stands are not only used for drilling holes at angles with the remaining holes to be drilled, but sometimes such stands are made to suit the jig in cases where it would be inconvenient to provide the jig with feet, finished bosses, or lugs, for resting directly on the drill-press table.

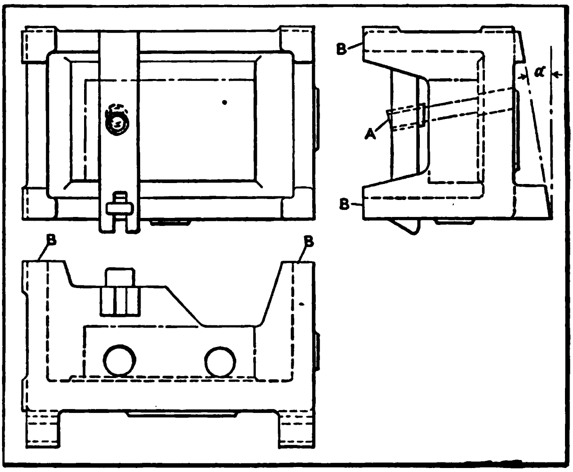


Fig. 12. Jig for Drilling Holes at an Angle

When a jig of large dimensions is to be turned over, either for the insertion or removal of the work, or for drilling holes from opposite sides, it is, in cases where the use of a crane or hoist can be obtained, very satisfactory to have a special device attached to the jig for turning it over. Fig. 14 shows such an arrangement. In this illustration, *A* represents the jig which is to be turned over. The two studs *B* are driven into the jig in convenient places, as nearly as possible in line with a gravity axis. These studs then rest in the yoke *C*, which is lifted by the crane hook placed at *D*. The jig, when lifted off the table, can then easily be swung around. The yoke is made simply of round machine steel.

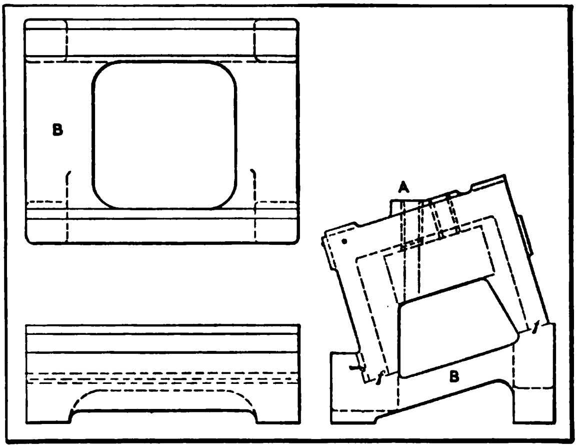


Fig. 13. Jig and Stand for Drilling Holes at an Angle

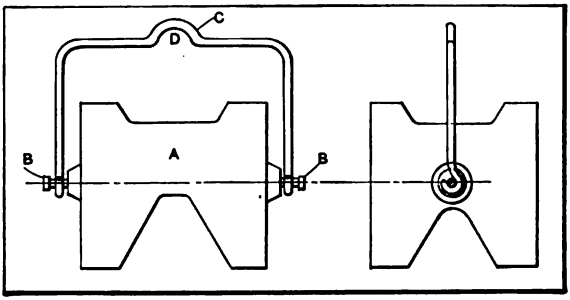


Fig. 14. Device for Turning over and Handling Heavy Jigs

Examples of Closed or Box Jigs. — The development of a closed or box jig has now been treated. In the following pages a number of examples of closed jig designs will be shown and described. There is, however, no distinct division line between open and closed drill jigs, so that in many cases it is rather inconsistent to attempt to make any such distinction.

In Fig. 15, for instance, is shown a box jig which looks like a typical open jig. The jig body *A* is made in one solid piece, cored out as shown, in order to make it lighter. The piece to be drilled, *B*, shown inserted in the jig, has all its holes drilled in this jig, the holes being the screw holes *C*, the dowel pin holes *D*, and the large bearing hole *E*. The bosses of the three screw holes *C* are also faced on the top, and the bearing is faced on both sides while the work is held in the jig. The work is located against two dowel pins driven into the holes *F*, and against two lugs at *G*, not visible in the illustration, located on either side of the work. In these lugs are placed set-screws or adjustable sliding points. It may seem incorrect not to locate the bracket in regard to the hole *E* for the bearing, so as to be sure to bring the hole concentric with the outside of the boss. This ordinarily is a good rule to follow, but in this particular case it is essential that the screw holes be placed in a certain relation to the outline of the bracket in order to permit this to match up with the pad on the machine on which the bracket is used. Brackets of this shape may be cast very uniformly, so that locating them in the manner described will not seriously interfere with drilling the hole *E* approximately in the center of its boss. The work is firmly held in the jig by the three straps *H*, care being taken in designing the jig that these straps are placed so they will not interfere with the facing tools.

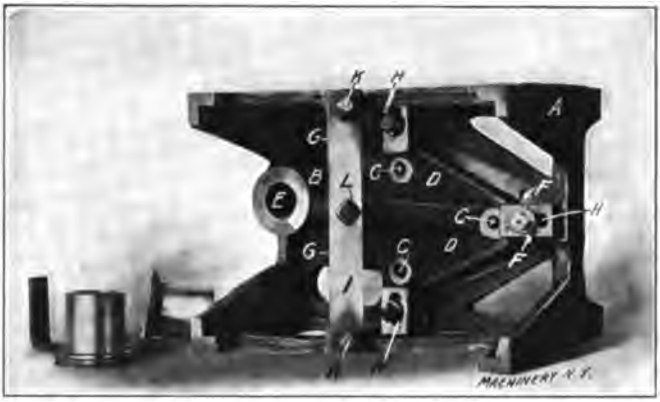


Fig. 15. Box Jig which Resembles the Open Type

The swinging strap *I*, which really is the only thing that makes this jig a closed jig, serves the sole purpose of taking the thrust of the heavy cutting tools when drilling the hole *E* and of steadying the work when facing off the two ends of the hub. The two collar-head screws *K* hold the strap to the jig body and the setscrew *L* bears against the work. This strap is easily swung out of the way by loosening one of the collar-head screws, a slot being milled at one end of the strap to permit this. Stationary bushings are used for the screw hole and dowel holes, but for the bearing hole *E* three loose bushings and a lining bushing are employed.

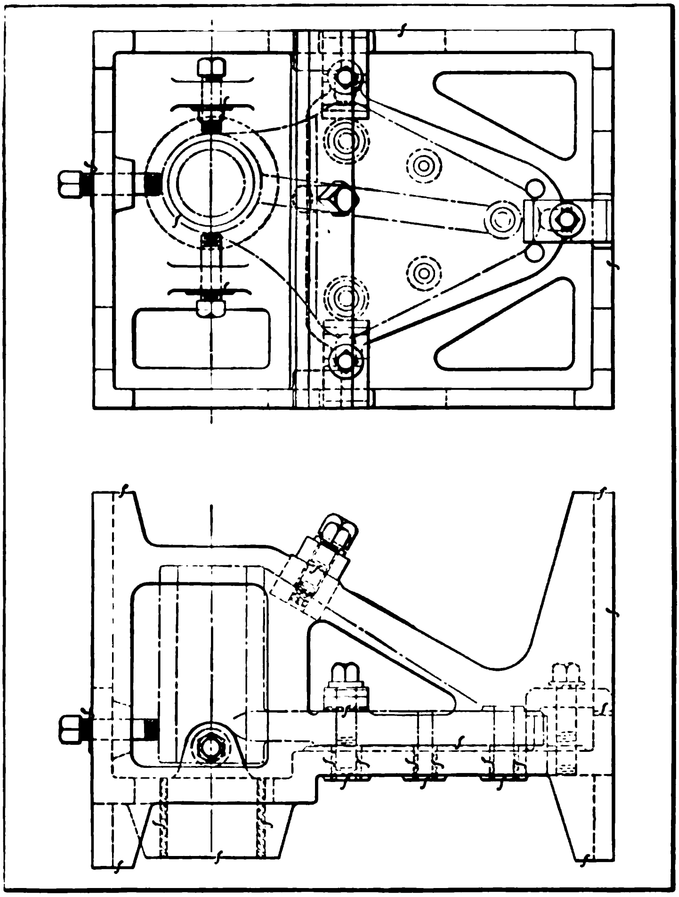


Fig. 16. Plan and Elevation of Jig Shown in Fig. 15

The hole *E* is first opened up by a small twist drill, which makes the work considerably easier for the so-called rose-bit drill. The latter drill leaves $\frac{1}{16}$ inch of stock for the rose reamer to remove, which produces a very smooth, straight, and concentric hole. The last operation is the facing of the holes. The holes just drilled are now used to guide the pilots of the facing tools, and, as the operation is performed while the work is held in the jig, it is important that the locating or strapping arrangements should not be in the way.

In connection with the opening up of a hole with a smaller drill, it may be mentioned that it is not only for large holes that this method of procedure will save time, but the method is often a time-saving one also for smaller holes, down to $\frac{1}{4}$ inch in diameter, when drilled in steel.

The use of lubrication in jigs is a very important item, the most common lubricant being oil or vaseline, but soap solution is also used. The objection to the latter is that unless the machine and tools are carefully cleaned it is likely to cause rusting. Using a lubricant freely will save the guiding arrangements, such as the drill bushings, the pilots on counterbores, etc., to a great extent.

The jig in Fig. 15 is shown in Fig. 16 and a clear idea of the design of the jig will be had by studying this line engraving. The bracket *B*, in Fig. 15, could have been drilled in a different way than described, which would sometimes be advantageous. It could be held in a chuck, and the hole *E* reamed and faced in a lathe, which would insure that the hole would be perfectly central with the outside of the boss. Then a jig could be designed, locating the work by a stud entering in hole *E*, as indicated in Fig. 17, additional dowel pins and set-screws being used for locating the piece sidewise. The whole arrangement could be held down to the table by a strap and bolt, a jack-screw supporting it at the overhanging end.

Fig. 18 shows another jig of the closed type, with the work inserted. The piece *A* is a casing, and the holes to be drilled vary greatly in size. The casing rests on the flat, finished bottom surface of the jig and is brought up squarely against a finished pad at *B*. It further locates against the finished lug *C*, in order to insure getting the proper amount of metal around the hole *D*. At the bottom it is located against the sliding point *E*, the latter being adjustable, because the location of the work is determined by the other locating points and surfaces. The work is held against the locating points by the long set-screw shown to the left. This clamping arrangement, however, is not to be recommended, because this screw must be screwed back a considerable distance in order to permit insertion and removal of the work.

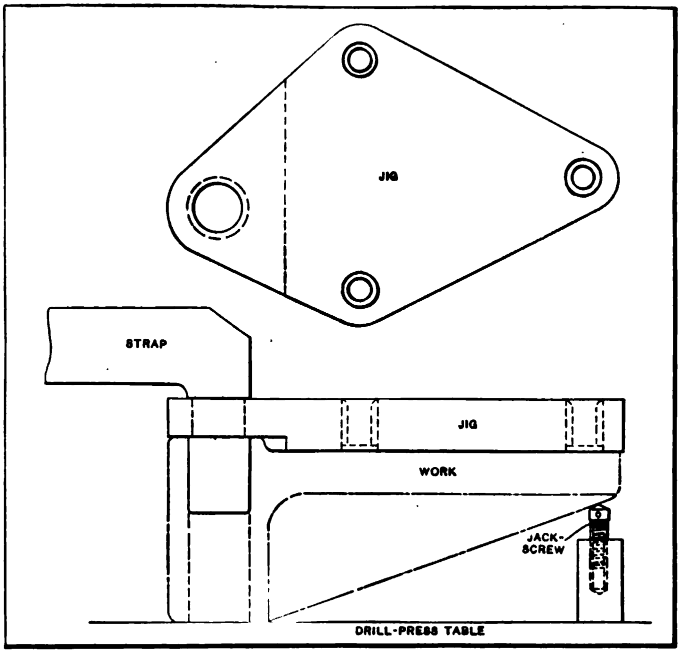


Fig. 17. Simple Plate Jig for Drilling Bracket shown in Fig. 15, after Hole E has been Bored in the Lathe

An eye-bolt used in the manner described in a preceding chapter would have given better service. The three straps *G* hold the work against the bottom surface, and the two straps *H* hold it against the finished surface at *B*. There is not a long finished hole through the casting, as would be assumed from its appearance, but simply a short bearing at each end, the remaining part of the hole being cored out. For this reason, the hole is drilled and reamed instead of being bored out, as the latter operation would be a slower one. Although the two short bearings are somewhat far apart, the guiding bushings come so close to these bearings that the alignment can be made very good. The screw holes and dowel pin holes at the bottom of the casing are not shown in the illustration, as the inserted casing is not yet drilled. The hole drilled from bushing *I* is a rather important hole, and the bushing requires a long bearing in order to guide the drills straight when drilling. When this jig was made, the projecting lug which was provided solid with the jig body, to give a bearing to the jig bushing, came so much out of the way in the rough casting for the jig that half of the lining bushing would have been exposed. It was therefore planed off and a bushing of the type shown in Fig. 5, in the chapter on "Jig Bushings," inserted instead, in order to provide for a long bearing.

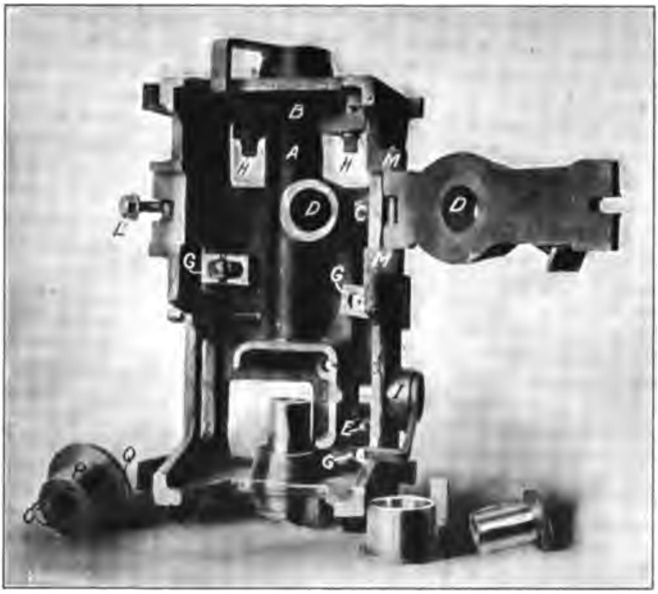


Fig. 18. Box Jig for Casing drilled from Five Directions

Leaf *K*, which carries the bushings for drilling the hole *D*, fits into a slot planed out in the jig body and is held down by the eye-bolt *L*. Two lugs *M* are provided on the main casting for holding the pin on which the leaf swivels. Around the hole

D there are three small tap holes *O* which are drilled by the guiding afforded by the bushing *P*, which is made of cast iron and provided with small steel bushings placed inside as illustrated in Fig. 14, in the chapter on "Jig Bushings." In the bushing *P* is another hole *Q* which fits over a pin located in the top of the leaf and which insures that the three screw holes will come in the right position. It should be noted that large portions of the jig body are cored out at top and bottom in order to make it light and easy to handle. Of course some metal is also saved by the construction of jigs in this manner, but comparing the price of cast iron with the total price of a finished jig of this type, the saving in this respect is so insignificant that it is not worth while mentioning. The leaf *K* is also made of cast iron, being of

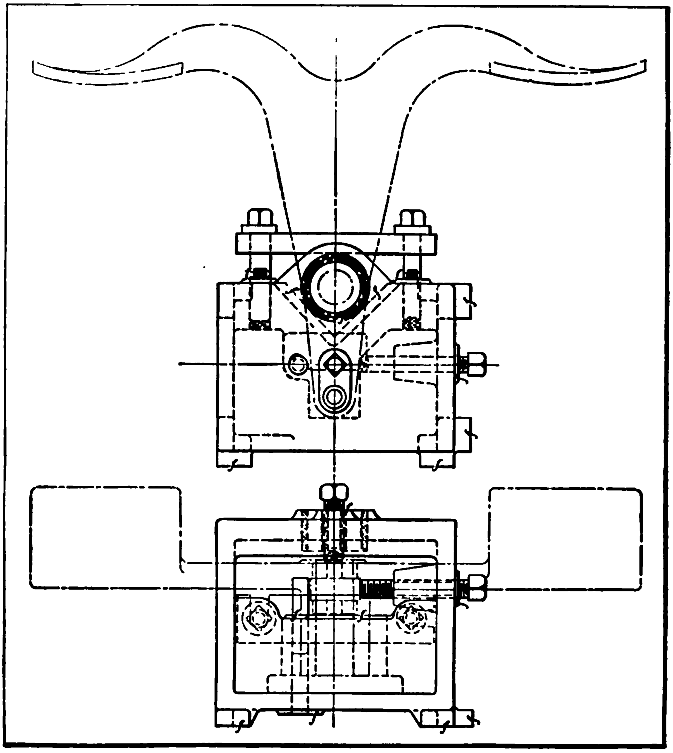


Fig. 19. Box Jig for Drilling Work shown by Dash-dotted Lines

particularly large size, and it is planed at the places where it has a bearing on the jig body.

Fig. 20 shows a closed jig about which there can be no doubt but that it should be classified as a box jig. The piece of work drilled, the foot trip *A*, has two holes *B* and *C* which are drilled in this jig. The cylindrical hub of the work is located against V-blocks and held in place by a swinging strap *D*. The work is further located against a stop-pin placed opposite the set-screw *E*. The trip is located sidewise by being brought against another stop by the set-screw *F*. One-quarter of a turn of the collar-head screw on the top of the jig releases the swinging strap which is then turned out of the way; this permits the trip to be removed and another to be inserted. Half a turn or less of the set-screws is enough to release and clamp the work against the stops mentioned. A line engraving of this jig is shown in Fig. 19 which gives a better idea of some of the details of the construction.

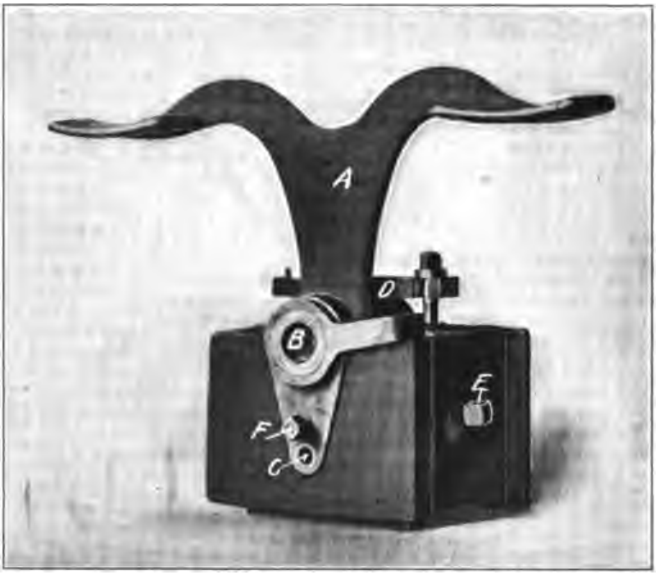


Fig. 20. Jig shown in Detail in Fig. 19

In Figs. 21 and 22 are shown two views of another type of closed drill jig. The work *A*, to be drilled, is shown at the left in both illustrations, and consists of a special lathe apron with large bearing holes, screw holes, and dowel pin holes to be drilled. The apron is located in the jig body in the same manner as it is located on the lathe carriage, in this case by a tongue which may be seen at *B* in Fig. 22. This tongue fits into the slot *C* in the jig, care being taken in the construction of the jig that the slot is made deep enough to prevent the tongue from bearing in the bottom of the slot. A good solid bearing should be provided, however, for the finished surface on both sides of the tongue. The surface *D* should also have a solid bearing on the surface *E* in the jig, the difference in height between the two bearing surfaces in the jig being exactly the same as between the two bearing surfaces on the lathe carriage where the lathe apron is to be fitted. The work is brought up against, and further located by,

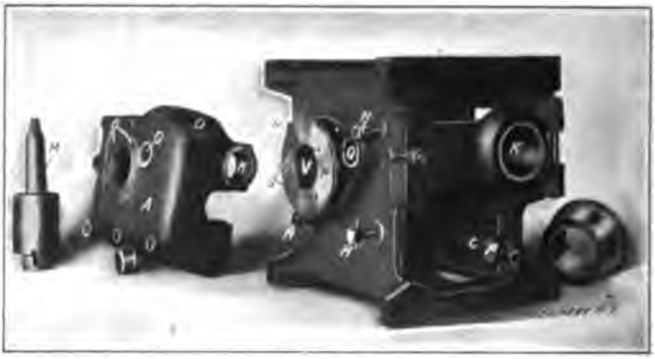


Fig. 21. Jig of Typical Design, and Work for which it is Used

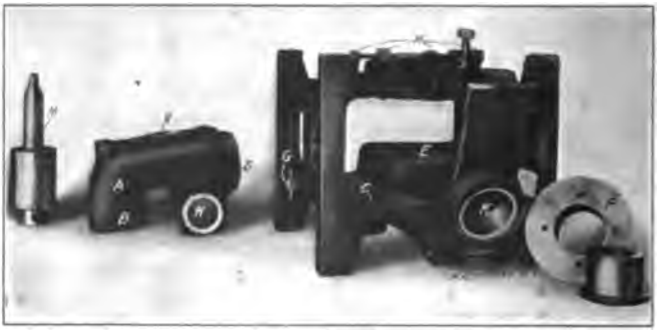


Fig. 22. Another View of the Jig in Fig. 21

a dowel pin at the further end of the slot, by the set-screw in the block *F*, Fig. 21. As it is rather difficult to get the tongues on all the pieces exactly the correct width for a good fit in the slot, the latter is sometimes planed a little wider and the tongue is brought up against one side of the slot by set-screws. In the case in hand, a few thousandths inch clearance is provided in the slot, and the set-screw *G* in Fig. 22 is used for bringing the work against the further edge, which stands in correct relation to the holes to be drilled. The apron is held down against the bottom surface of the jig by four heavy set-screws *H*.

It will be noticed that the jig is open right through the sides in order to facilitate the finishing of the pads at the ends of the work, and a swinging leaf, like the one previously described, reaches across one side for holding the lining and loose bushings for the hole *K* which is drilled and rose-reamed in the usual way. The large hole *V*, Fig. 21, is bored out with a special boring tool *M*, as there are no standard drills obtainable for this large size of hole. This special boring tool is guided by a cast-iron bushing which fits into the lining bushing; it is provided with two cutters, one for roughing and one for finishing. The small screw holes *O* around the large hole *V* are drilled from the bushing *P*. For drilling the rest of the holes, except the hole *Q*, stationary bushings are used. The screw holes ought to be drilled simultaneously in a multiple-spindle drill. The jig is provided with feet and cored out in convenient places in order

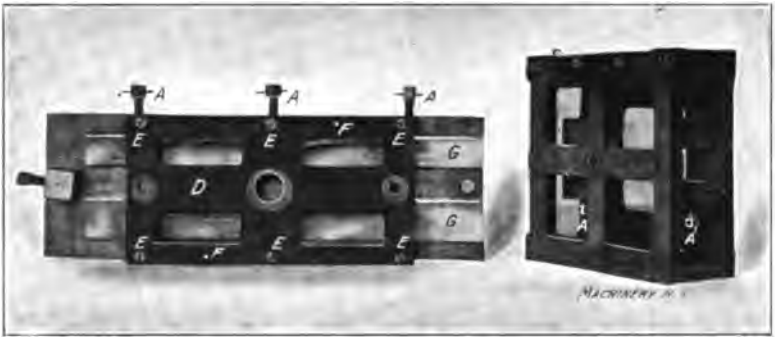


Fig. 23. Jigs in which the Work is Located by Means of Beveled Surfaces

to make it as light as possible to handle. Lugs project wherever necessary to give ample bearings to the lining bushings and, in turn, to the loose guiding bushings.

Fig. 23 shows two closed jigs made up of two main parts which are planed and assembled by screws and dowels as indicated, the reason for making the jigs in this way being the ease of planing the bottom section. The work drilled in these jigs, some special slides, is located by the dovetail and held up against one dovetail side by set-screws *A*, as shown in the illustration. In the jig to the left, the work is located endwise against a dowel pin and is held up against this stop by a set-screw through the block shown to the left. This block must be taken out when the slide is inserted, this being the reason why a lug cast directly in place, through which the set-screw could pass, is not used. The top plate *D* is held down on the main body by six fillister-head screws *E*, and two dowel pins *F* prevent it from shifting. No clamping arrangements, except the set-screws *A*, are necessary. The holes being drilled from the top, the main body of the jig takes the thrust. These jigs are also used in multiple-spindle drills.

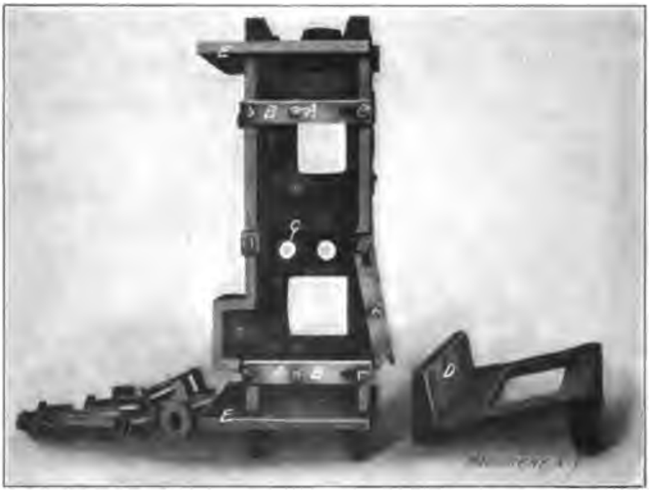


Fig. 24. Jig for Drilling Holes at other than 90-degree Angles

One objectionable feature of the jig to the right in Fig. 23 is that set-screws *A* are difficult of access. There are, therefore, holes piercing the heads of the set-screws in two directions in order to allow a pin to be used when tightening the screws. A better idea, however, is to have the screw-heads extend out through the wall and, if this is solid, to have cored or drilled holes through which the heads of the screws may pass.

In Fig. 24 is another closed drill jig in which the work is located against the finished seats and held down by the set-screws *A* in the straps *B*. All the holes, except those marked *C*, are drilled in the usual manner, the jig standing on its own feet, but when drilling the holes *C*, which come on an angle, the special stand *D* is employed, which brings the holes in the right position for drilling, as illustrated in Fig. 25. If only the holes *C* were to be drilled, the feet on the side opposite the guiding bushings for these holes could have been planed off, so that they would have been in a plane perpendicular to the axis of the holes. This last jig has a peculiar appearance, on account of the end walls coming up square, as shown in the illustrations, but this design was adopted only to simplify matters for the patternmaker, it being easier to make the pattern this way.

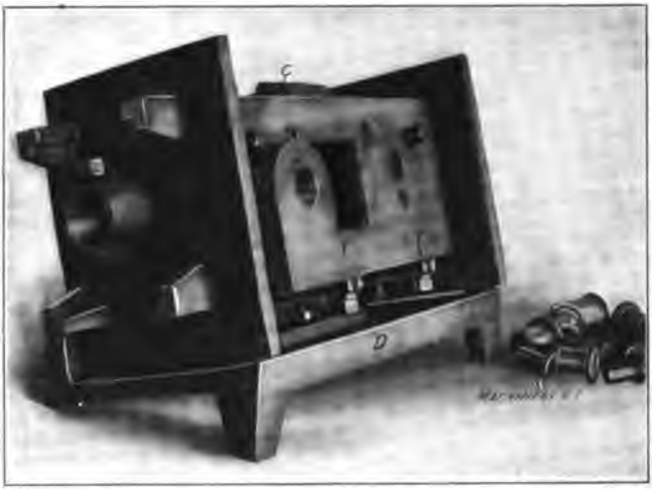


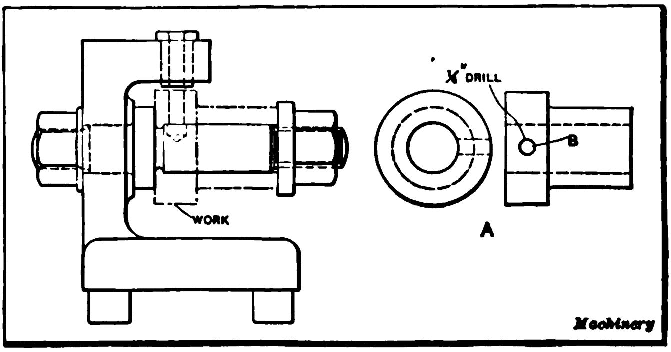
Fig. 25. Jig in Fig. 24 in Position for Drilling Holes at an Oblique Angle with Jig Base

CHAPTER XIII

SPECIAL JIG AND FIXTURE MECHANISMS

No single item influences the production rate to as great an extent as the design of jigs and fixtures. The saving of a few seconds clamping time means an increased production that offsets a high first cost. It is much easier for an operator to clamp his work by tightening one nut than the usual three, and, aside from the saving of time, he is expending less energy and works to better advantage to himself and his employer.

It is usually necessary to equalize the pressure in a jig before applying the clamping pressure. When equalizing and clamping mechanisms are both operated by a single clamping operation, the danger of clamping before equalizing the pressure can be eliminated. Many object to the term "fool-proof," but the amount of work spoiled or sprung by careless clamping justifies care in designing jigs and fixtures that are at least "error-proof" in this respect.



Machinery

Fig. 1. Simple way of Clamping a Bushing for Drilling

The mechanisms described in this chapter are selected for their suggestive value, and only as much of the fixture is shown as is absolutely necessary. Great care should be used in selecting the mechanism desired, so that it meets the clamping or equalizing conditions of the work in hand. The examples shown are in many cases obtained from milling fixture designs, but the principles apply equally to drill jigs.

As an example in the choice of clamping mechanism, consider the piece *A*, Fig. 1. It is required to drill the hole *B*. A simple way of clamping this piece is illustrated in Fig. 1, using a hexagon nut and washer. The time required for running on and off the hexagon nut is saved in the design shown in Fig. 2, using a quarter-turn knob. Stud *B* has a flat milled on both sides of its threaded portion. The slot in knob *A* slides on over this flat and a quarter turn clamps the work. If the variation in the length of the work is not too great, this makes a rapid clamping arrangement.

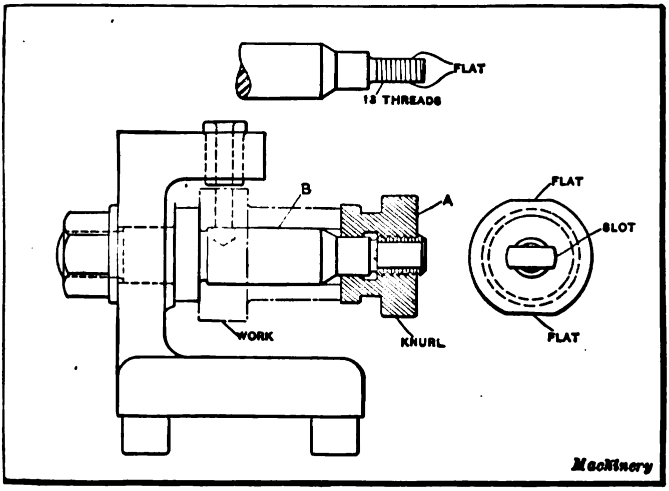


Fig. 2. Using a Quarter-turn Knob for Clamping the Work

Fig. 3 shows another means of clamping the same piece, in which the variation in length of the work and the time required for turning the knob to match the flat on the stud has been considered. The slotted washer *A* and knob *B* are dropped over stud *C*; washer *A* is held against knob *B*, which can then be screwed up as freely as a solid knob. This can be used for a variety of bushings of various lengths, the stud *C* being made to suit the longest piece of work.

Clamps that have a tendency to draw the work down firmly onto the rest-pins or stops are useful in all classes of fixtures. Fig. 4 illustrates a simple means of accomplishing this. Care should be taken to see that the stop is pivoted above the point *A*. Another and more rigid device is illustrated in Fig. 5. The plunger *A*, carried in plunger *B*, is forced down against the 45-degree side of stop *C*, compressing spring *D*. A fixture that clamps two clamps with a "down-and-in" pressure is illustrated in Fig. 6.

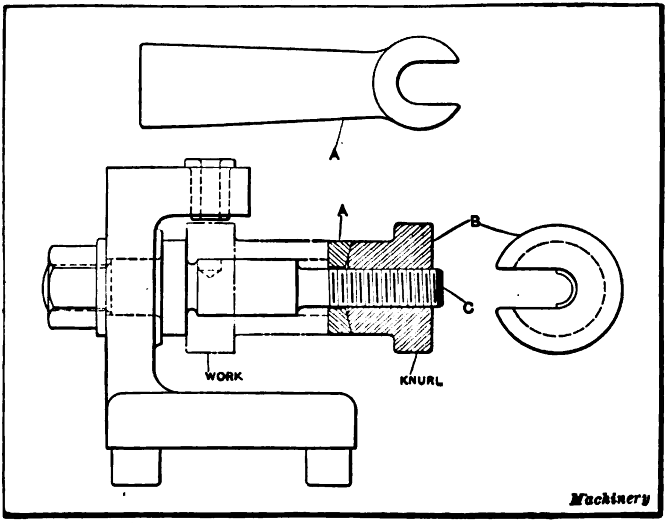


Fig. 3. Means used for Clamping Bushing when the Work Varies in Length

Slides *B* are equalized by strap *C* and ball-and-socket washers *D* and *E*. This fixture is useful for milling and profiling, as the clamps and stops are below the surface of the work. Fig. 7 shows two down-and-in clamps equalized for holding a round piece of bored work for a milling operation. Lever *A* is tapped to receive screw *B*, and the clamping pressure equalizes with lever *C* by means of rod *D*. Levers *A* and *C* impart a down-and-in pressure to plungers *E*. This fixture can be applied to flat work.

In the double movement clamp shown in Fig. 8, the clamp *A* is carried by the hinge *B*, pivoted at *C*. Screw *E* gives clamp *A* a down-and-in movement by means of a 45-degree taper on stud *D*. The stud *D* is milled off at *F* to give the clamp sufficient movement to remove the work. A mechanism for drawing down both ends of two pieces, by means of a single nut, is illustrated in Fig. 9. Each piece is clamped independently, thus making it suitable for use on rough castings or forgings. Rod *A*, running through the fixture, carries ball-and-socket washers at each end and draws the end clamps *B* and *C* together. These clamps are given a down-and-in movement against the 45-degree wedge ends of rods *D* and *E*. The clamping thrust against rods *D* and *E* imparts a downward movement to the inner clamps *G* and *H*, pulling the work down on the inner rest-pins. The clamps are returned by means of plungers *K* and spring *J*.

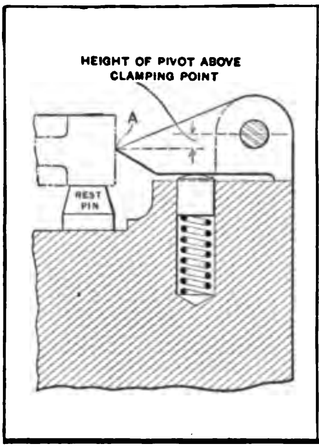
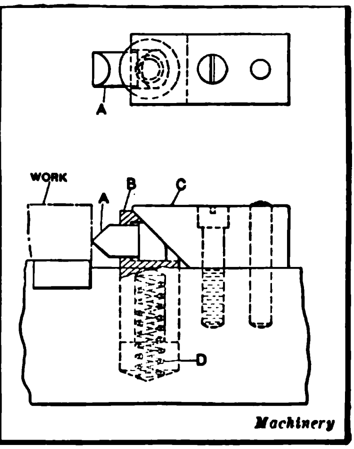


Fig. 4. Simple means for Drawing the Work down Firmly onto the Locating Pins



Machinery

Fig. 5. Another Example of Clamps Drawing the Work down Firmly onto the Locating Pins

The fixture illustrated in Fig. 10 shows a method of drawing down two clamps and throwing the work against the stop-pin by a single clamping operation. Tightening nut *A* clamps down clamp *C* and pulls up rod *B* against the 45-degree tapered end of rod *D*, giving a lateral movement against plunger *E*. Plunger *E* is carried by the floating stud *G*. On the upper end of stud *G* is a 15-degree taper that operates against plunger *H*. Plunger *E* imparts, first, an upward movement to floating stud *G*, which,

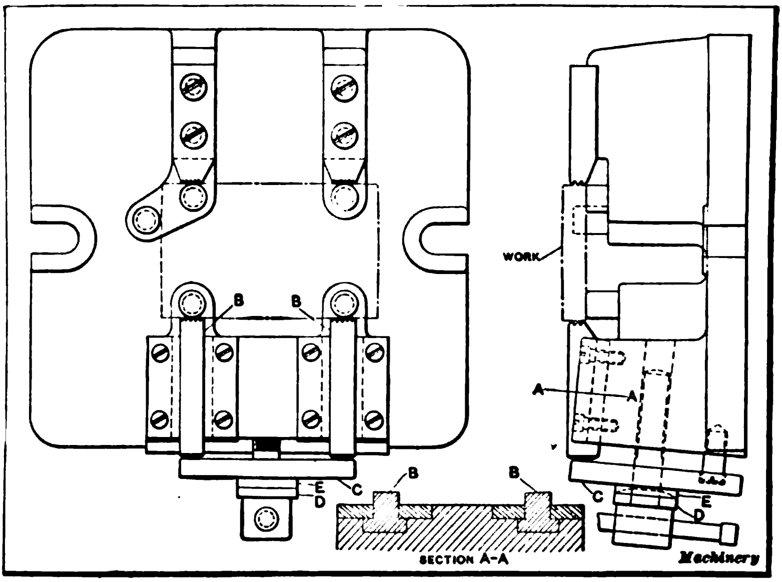


Fig. 6. Fixture with Arrangement for Clamping Two Clamps with a "Down-and-in" Pressure

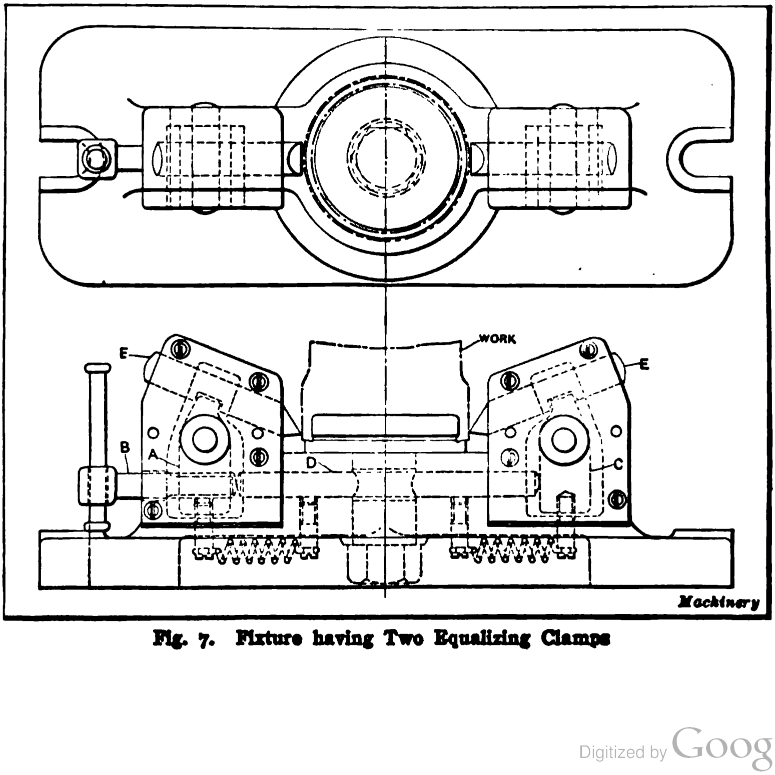


Fig. 7. Fixture having Two Equalizing Clamps

in turn, forces out plunger *H* and throws the work against stop-pin *J*; second, a downward pull on plunger *K*, drawing down the clamp *L*. Thus the work is thrown against the stop-pins before the final clamping pressure is applied. Clamps *C* and *L* are held up by spring plungers, not shown.

The clamping pressure on eight small washers is equalized, and the washers clamped with a down-and-in movement in the fixture shown in Fig. 11. Rod *A* clamps the equalizers *B* and *C*, which equalize the pressure against *D* and *E* on the one side, and *F* and *G* on the other. Clamps *D*, *E*, *F*, and *G* are given a downward pull by four plungers *H*, which also impart a downward pull on the inner clamps *J*, *K*, *L*, and *M*. The clamps are bored to receive the washers, and are returned to a normal position by the spring plungers *N*.

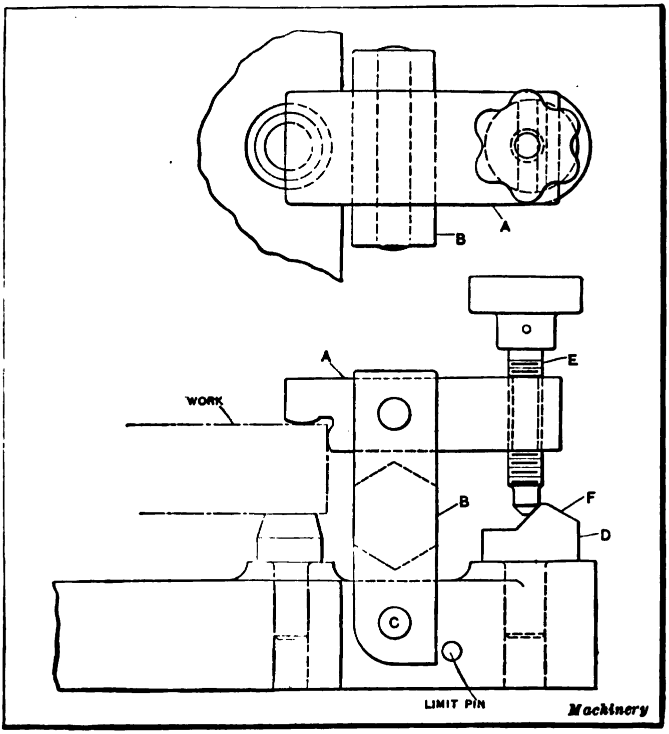


Fig. 8. Another Type of Double Movement Clamp

Fig. 12 illustrates a center clamp that gives a downward and outward thrust by means of the tapered ends of plate *A*, which is carried by plunger *B*. Plunger *C* wedges down the plunger *D*, which is tapped into plunger *B*. Plungers *B* and *D* are held up by a spring *E*. A small pin in plunger *D* allows a half turn of plunger *B*, so that the work may be lifted out.

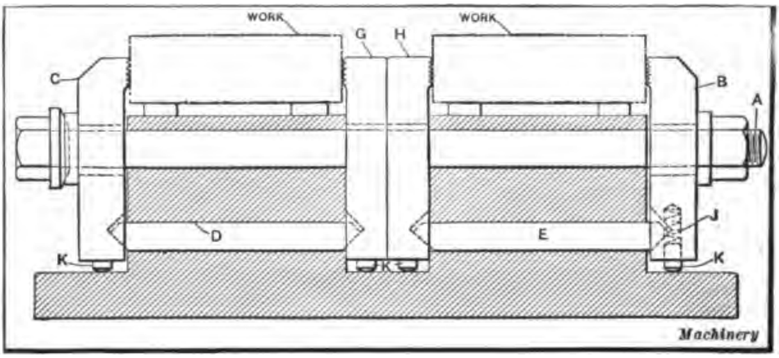


Fig. 9. Mechanism for Drawing down Both ends of Two Pieces by a Single Nut

In the fixture illustrated in Fig. 14, the work (two clutch shells) is equalized and clamped by a single movement of the handwheel *B*, drawing out rod *C* against the collar *D*. The section *A–A* shows how this collar equalizes its thrust with plungers *E* and *F*. The collar *D* is free to slip to either side as required for equalizing. The plungers *E* and *F* draw in rods *G* and *H* through

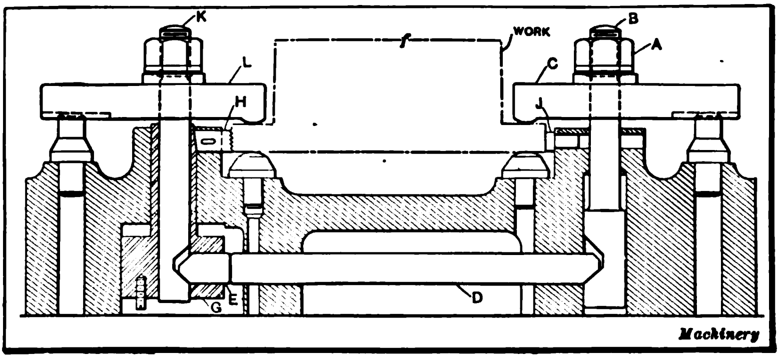


Fig. 10. Method for Drawing down Two Clamps and Forcing the Work against the Stop-pin by a Single Clamping Operation

the medium of collars *J* and *K*. The strap *M*, held central by a small spring and plunger, equalizes the pull on the center clamp. All clamps are made to clear the work, when it is to be removed, by means of the lever *L* and the system of levers shown in the lower view.

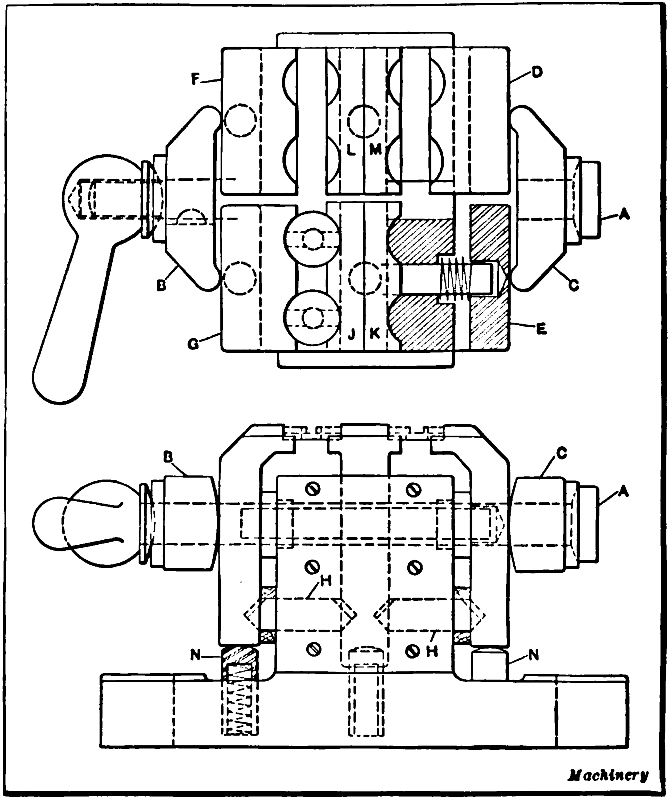


Fig. 11. Fixture for Equalizing the Clamping Pressure on Eight Small Washers

Figs. 13 and 15 illustrate a small double movement clamping mechanism for hand milling or profiling use. In Fig. 13, the clamping pressure against clamp *A* also pulls out plunger *B*, throwing up plunger *C* and throwing the work against stop *E*, by means of plunger *D*. Spring plunger *G* is used to return plunger *D*. In Fig. 15, the pull through clamp *A* on plunger *B*

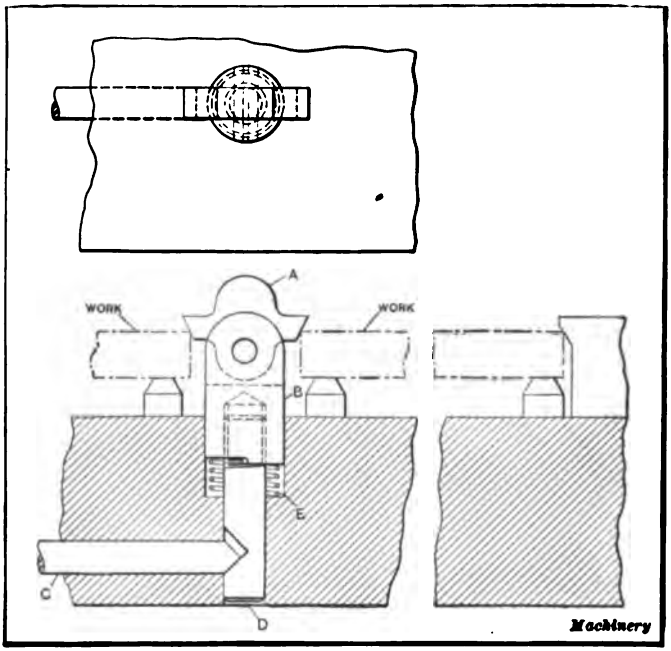


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Fig. 12. Center Clamp giving a Downward and Outward Thrust

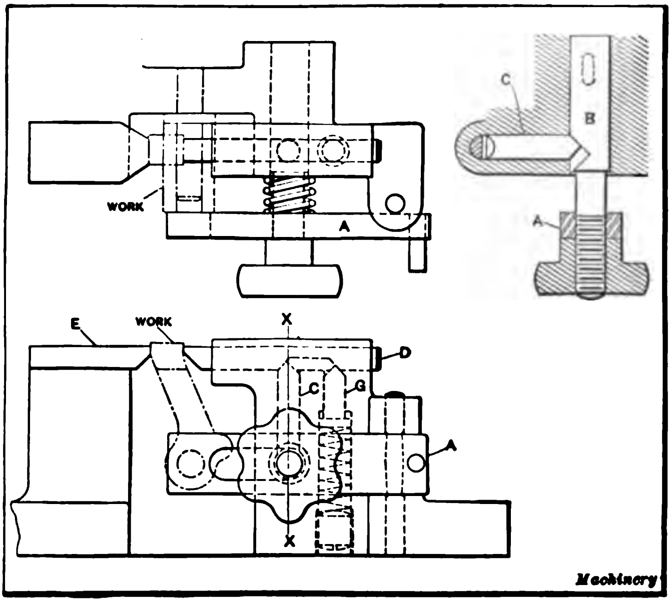

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Fig. 13. Small Double Movement Clamping Mechanism for Hand Milling or Profiling Machines

throws the work against the stop *C*, by means of plungers *D* and *E*.

In profiling or face milling fixtures, clamps on top of the work often interfere with the cutter. Fig. 16 illustrates a method of

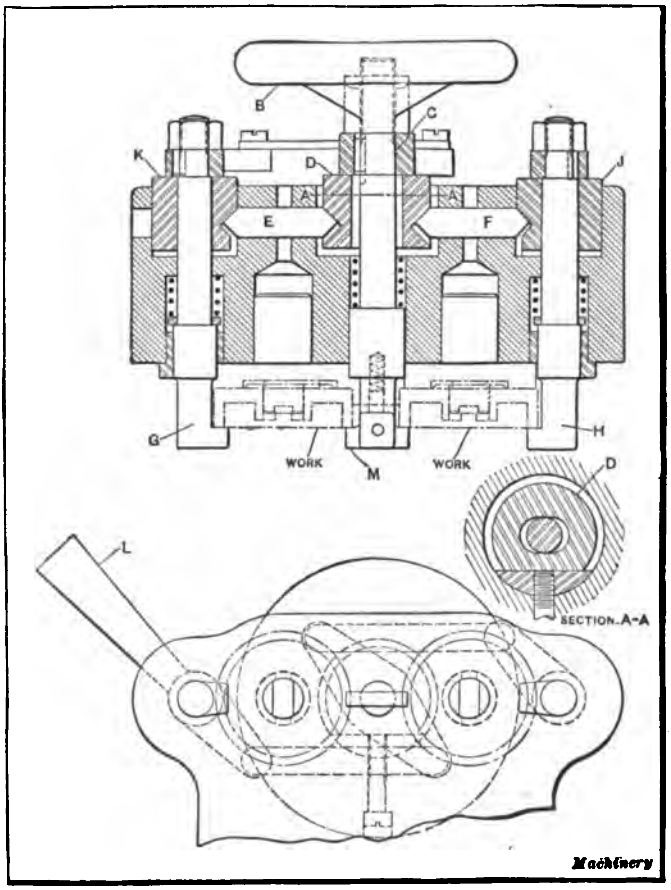

Fig. 14. An Equalized Clamping Arrangement making use of a Handwheel

holding this class of work by means of a flange at the bottom. Clamp *A* is operated by the wing-nut *B* and floats in slots to allow for any casting variation, and for hooking the projection on the clamp over the flange. The piece *C* is thrown over after the clamp is hooked over the flange. Care must be taken that the point *X* is below the pivot point of the piece *C*.

Fig. 17 illustrates part of a heavy milling fixture for clamping against the stop-plate *A*, by means of the two plungers *B* and *C*, by equalizing with the plunger *D* and sleeve *E* working against *B* and *C* with 45-degree wedge cuts. Projections on the work often prevent the use of plain clamps. Fig. 18 shows a resort to an unusual, but efficient, clamp to meet these conditions. The use of plungers *A* and *B* permits the clamp to be operated from the rear by means of a screw *C* and knob *D*. When work is long in proportion to its width or when the locating pins must be placed close together, as in the piece illustrated in Fig. 19, there is danger of it "cocking" or binding between one locating pin and the screw, if a plain screw is used to throw the work

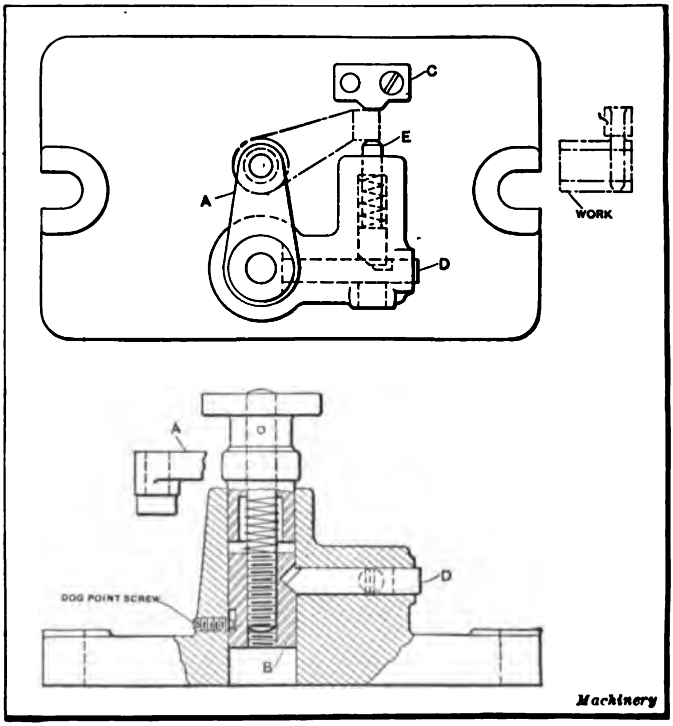

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Fig. 15. Another Double Movement Clamping Mechanism

against the locating pins. The use of a roller instead of a screw prevents this. The roller *A* will turn until the work strikes both stop-pins. In the device illustrated, *B* and *C* are the fixed locating pins, and *D*, the clamp screw tapped into the bushing

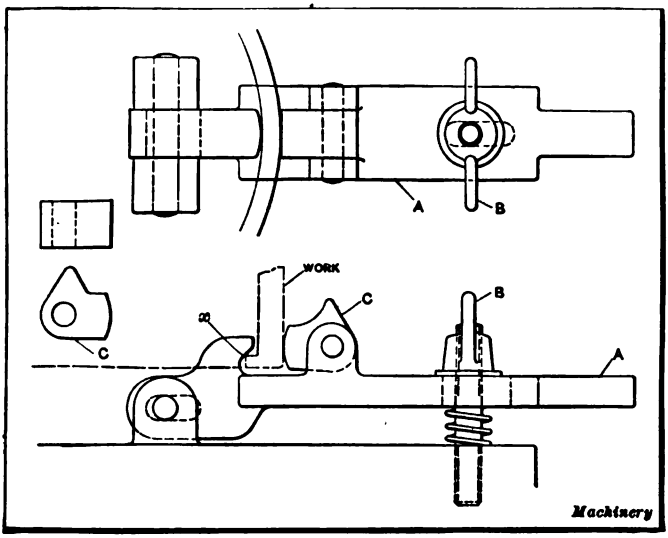

Fig. 16. Clamping Work by Holding it by Means of a Flange

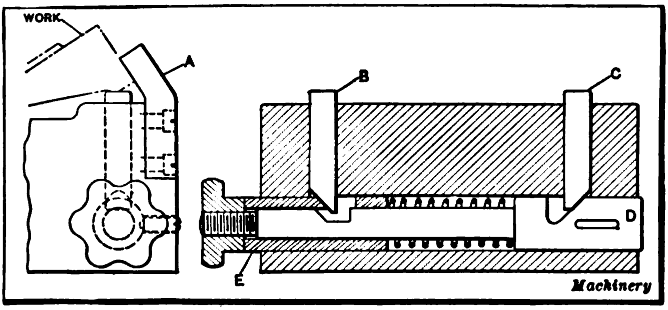

Fig. 17. A Heavy Milling Fixture with Equalizing Clamping Device

E operating the sliding plunger *G*. It is obvious that the work can be prevented from binding by using two equalizing plungers to throw it against the locating pins instead of a roller.

Fig. 20 shows the locating mechanism for a milling fixture in which two pieces are located by two plungers each, all operated

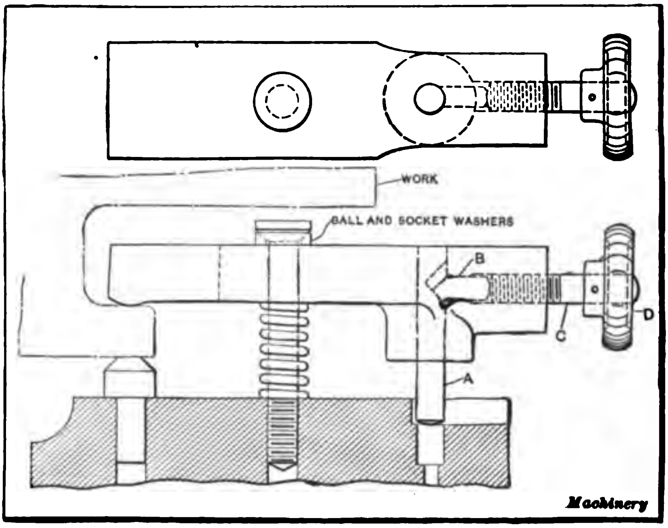

Fig. 18. Special Type of Clamp used where Projections on the Work Prevent the use of Plain Clamps

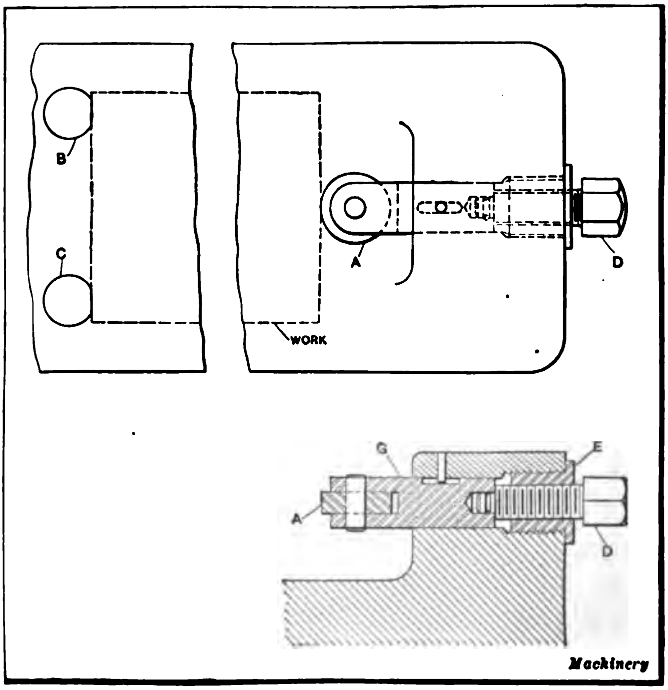

Fig. 19. Using a Roller to Prevent Unequal Binding against the Locating Pins

by a single clamping operation. Lever *A* draws out plunger *B* and throws in sleeve *C*, operating the plungers *D* and *E*. Plungers *E* are smaller in diameter than plungers *D* and permit of enough lateral movement to equalize plungers *G* through the auxiliary plungers *H*.

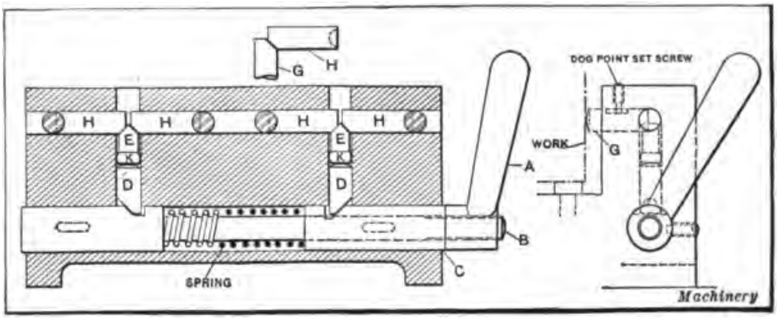

Fig. 20. Locating Mechanism where Two Pieces are Located and Clamped in a Single Operation

Fig. 21 represents a milling fixture with a quick-release feature. The particular work illustrated is milling a flat on a small bushing made on the screw machine. The bushings are held on the pins *A* and *B* and clamped with the eccentric handle *C*, which draws in the hinged leaf *D*. Details of the quick-release lever are given.

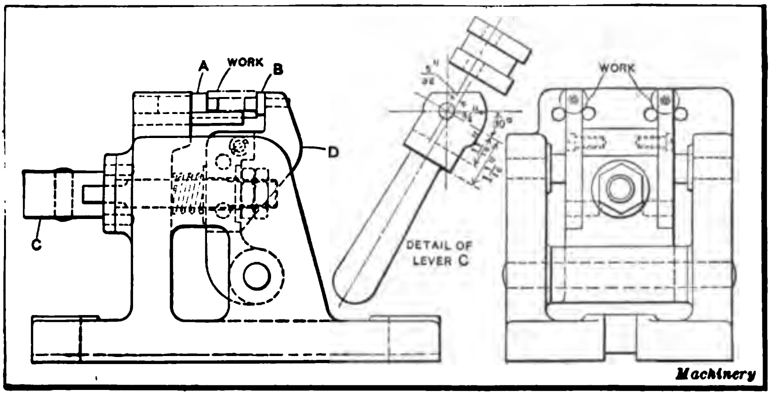

Fig. 21. Milling Fixture with a Quick-release Feature

Fig. 22 illustrates half of a fixture for milling a cylindrical concave surface on an unusual piece. The work is clamped against the pads *A* and *B*, on previously milled surfaces, by means of two differentially operated plungers *C* and *D*, similar to a previously described device. To prevent springing under cut, the work is backed up with the floating plunger *E* on the one side and *F* and *G* on the other. The plungers are operated by push-rods *H* and *J*. These push-rods are hand operated and are clamped by the bushing *K* and star knob *L*.

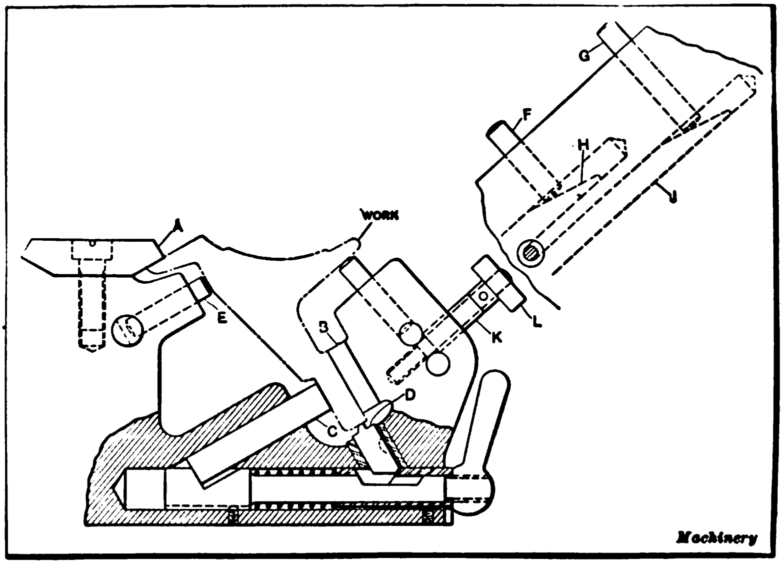

Fig. 22. Fixture for Milling a Concave Surface provided with Sliding Supports under the Milled Surface

Some occasions arise in which the 45-degree plungers do not permit of sufficient clamping movement. The mechanism in Fig. 23 was designed to overcome this objection. An unusually large movement of the clamp is required to clamp directly over the rest-pin. Rod *A*, operated by screw *B*, imparts movement to both plungers *C* and *D*. Plunger *C* pulls clamp *E* down and plunger *D* pushes up on clamp *E* through the plunger *G*. The wedge angle between plungers *C* and *D* should be less than that between plungers *A* and *C*. There is considerable friction in this mechanism.

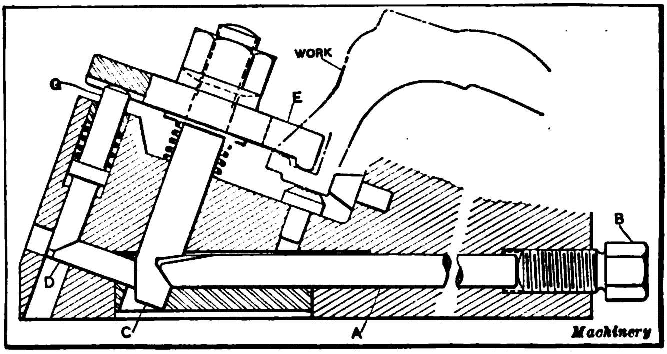

Fig. 23. Mechanism when an Unusually Large Movement of the Clamp is Required

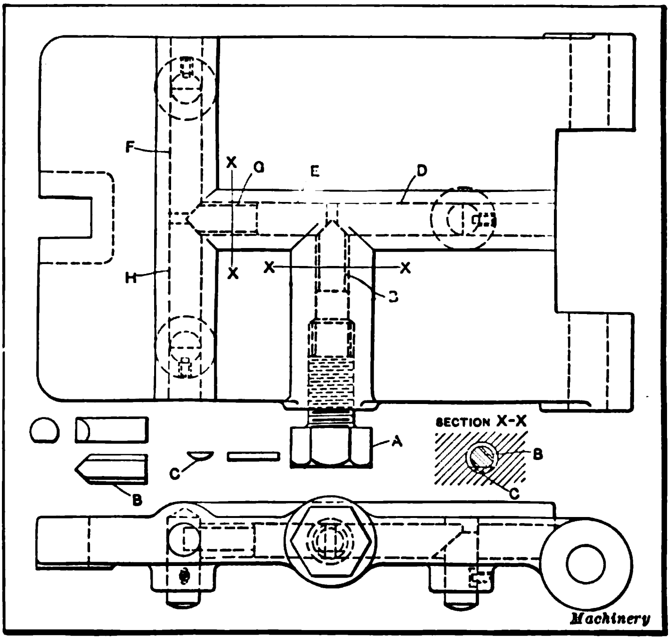

Fig. 24. Rigid Mechanism for Clamping at Three Points by Means of One Screw

A very rigid mechanism for clamping at three points, by means of one screw, is shown in Fig. 24. In this case, it is shown applied to a drill jig, but it is rigid enough to permit its use in milling or planing fixtures. In these cases, the clamping pins become rest-pins and are subject to the thrust of the cut. Screw *A* thrusts against equalizing plunger *B*. The details of this plunger mechanism are illustrated in the engraving. Plunger *B* is of less diameter than the drilled hole and rests on the piece *C*. This piece is cut from a rod of the same diameter as the hole and is used to afford a flat base for plunger *B* to rest on and insure full contact of the wedge end against the plungers *D* and *E*. Plunger *G* is a duplicate of *B* and equalizes the plungers *F* and *H* by means of the same mechanism.

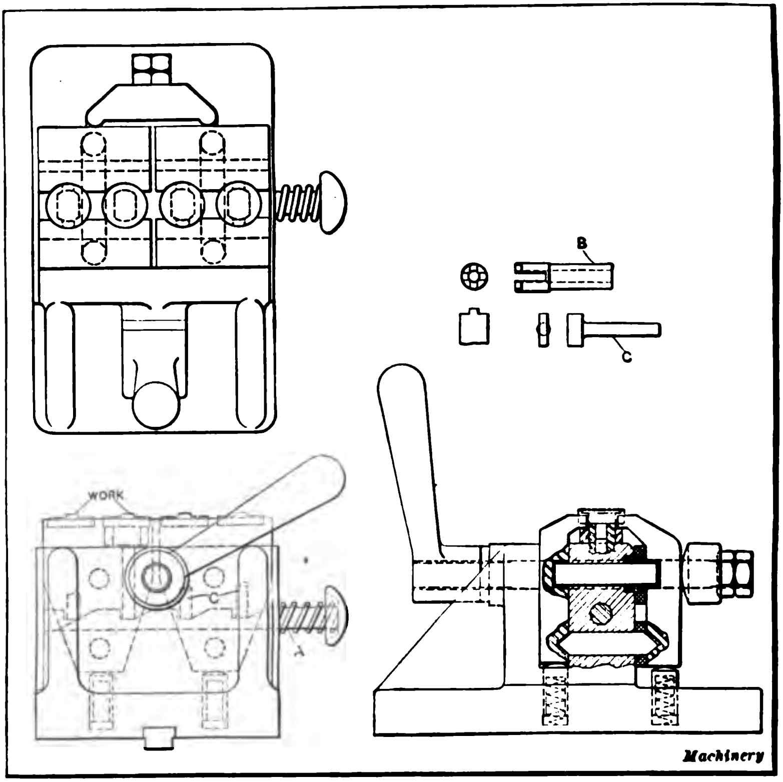

Fig. 25. A Simple Ejecting Device

Considerable saving of time may be effected by the use of ejectors. Fig. 25 is an example of the use of an ejector. Push-rod *A* has four notches milled tapering on one end. The pins

B are bored and slotted to receive the rods *C*. These rods are operated by the wedge cuts in push-rod *A*. The four pieces of work are ejected by pushing in rod *A*.

An element that has lately entered into shop equipment, and which must be constantly kept in mind by the tool-designer, is the safety-first movement. A milling cutter cannot be completely guarded and still perform its operation as a milling cutter. In work on Lincoln-type millers or on straddle-mill work, the return table movement must be long in order to eliminate the danger of the operator striking the cutters when unclamping or withdrawing the rear clamp. The necessity of the extra long table return is done away with in the straddle-milling fixtures illustrated in Fig. 26. The clamps are operated entirely from the front of the fixture, thus making it unnecessary for the operator to reach in near the cutters. Clamps *A* and *B* are operated

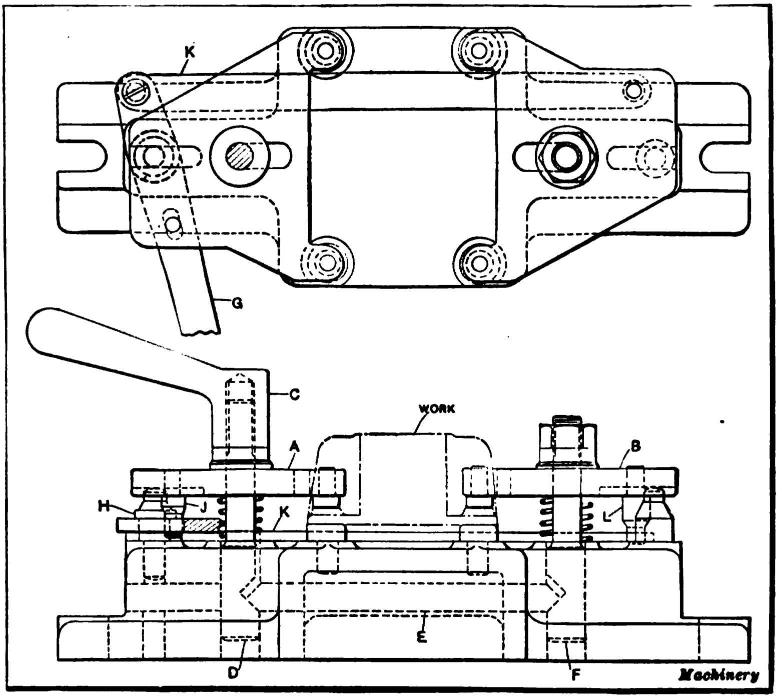

Fig. 26. Fixture Designed for use on Lincoln Milling Machine

by the handle *C* through stud *D*, rod *E*, and stud *F*. The clamps are withdrawn by lever *G*, which is pivoted on stud *H* and operates clamp *A* by means of pin *J*. The strap *K* is connected to the other end of lever *G* and operates the rear clamp by means of the pin *L*.

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